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# **Learning the Easy Way: The Role of Form Similarity in Language Learning and Processing**

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# Abstract

A key question about bilingual lexical access is whether lexical representations are activated selectively (within one language) or non-selectively (across languages). A great deal of the research addressing this question has focused on cognates, translation equivalents with the same or similar forms across languages. These studies show that, in non-native language (L2) processing, cognates are usually recognised and produced faster than non-cognates, suggesting that the form overlap between translation equivalents contributes to a processing advantage. Traditionally, the advantage is assumed to demonstrate on-line non-selective activation: For cognates, lexical activation stems from two sources rather than one, as is the case with non-cognates. This converging activation leads to their facilitated processing. However, some researchers argue that cognate facilitation could be due to differences in how cognates and non-cognates are learned, which leads to qualitatively different representations for cognates.

In this thesis, I focus on learning-based explanations of cognate effects and ask to what extent these can account for cognate facilitation. First, I review findings of cognate effects in both comprehension and production, evaluating whether they are more consistent with learning-based or on-line accounts. Second, I explore whether neural language models trained on two languages exhibit cognate facilitation and use this to test learning-based hypotheses of the effect. Following this, I present two behavioural experiments investigating cognate effects in human non-native speakers. The first investigates how the language of instruction affects cognate facilitation in trilinguals to examine whether cognate effects only occur between languages involved in learning. The second tests whether bilinguals exhibit cognate effects in L2 prediction to shed light on whether predictive processing is language selective. Taken together, this thesis provides evidence that cognate facilitation can, in principle, be explained by learning. I argue that while non-selective activation may occur during on-line processing, it is not required to explain cognate effects. I call for a more nuanced approach to theories of bilingual lexical access that allow for a more flexible role for language selectivity.

## Lay summary

Do bilinguals activate their native language when they hear or read words in their second language? This is an important question for understanding how bilinguals recognise words. Much of the research on this topic has focused on cognates — words that look or sound similar in two languages and have the same meaning (like *cat* in English and *kat* in Dutch). These studies show that bilinguals recognise cognates faster than non-cognates — words that have different forms in each language but the same meaning (like *dog* in English and *hond* in Dutch). This difference is often explained by the idea that both languages are active at the same time when bilinguals use their second language, giving cognates a processing boost because they are recognised in both languages.

However, some researchers argue that the cognate advantage might be due to how these words are learned, rather than both languages being active at once. In this thesis, I investigate whether the way cognates are learned can explain the cognate advantage. For instance, could it be that cognates are recognised faster because their form overlap makes them easier to learn, leading to better representations in memory compared to non-cognates? Or perhaps bilinguals learn cognates better because they encounter them more often in both languages? To explore these questions, I use both bilingual human participants and computer models that know two languages.

Overall, my findings suggest that learning plays an important role in bilingual word recognition. While both languages might still be active during processing, this is not necessarily the only explanation for the cognate advantage. I propose that we need more flexible theories of bilingual word recognition that consider how learning shapes the way bilinguals understand words across languages. This thesis challenges traditional views and provides new insights into how bilinguals juggle multiple languages in their minds.

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# Declaration

I declare that the thesis has been composed by myself and that the work has not been submitted for any other degree or professional qualification. I confirm that the work submitted is my own, except where work which has formed part of jointly-authored publications has been included. My contribution and those of the other authors to this work have been explicitly indicated below. I confirm that appropriate credit has been given within this thesis where reference has been made to the work of others.

The work presented in Chapter 2 was previously published in *Bilingualism through the Prism of Psycholinguistics* as *Can learning explain cognate effects in bilingual comprehension and production?* by Irene E. Winther (the undersigned), Yevgen Matusevych (supervisor), and Martin J. Pickering (supervisor). This theoretical review was conceived by Irene E. Winther and Martin J. Pickering. I carried out the majority of the literature review and preparation of the manuscript.

The work presented in Chapter 3 was previously published in the *43rd Proceedings of the Annual Meeting of the Cognitive Science Society* as *Cumulative frequency can explain cognate facilitation in language models* by Irene E. Winther (the undersigned), Yevgen Matusevych (supervisor), and Martin J. Pickering (supervisor). This study was conceived by Irene E. Winther and Yevgen Matusevych. I carried out the experimental work, formal analysis, and the majority of the preparation of the manuscript.

(Irene E. Winther)



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# Chapter 1

## Is Bilingual Word Recognition Always Non-Selective?

### 1.1 Introduction

One of the most important and general questions about bilingualism is the extent to which bilinguals keep their languages separate. To illustrate, if a Dutch–English bilingual reads an English text and encounters the word *room*, which means ‘cream’ in Dutch, are both meanings of this false friend automatically activated, or only the relevant English meaning? The former would suggest they integrate their languages, the latter that they keep them comparatively separate. This distinction reflects the hypotheses of *language non-selective* activation and *selective* activation. Non-selective activation means that lexical representations from both languages are activated simultaneously *on-line* during processing, whereas selective activation is constrained to representations from only the contextually relevant language, suggesting that the languages can be kept comparatively separate.

A considerable amount of relevant research on this topic has focused on cross-linguistic effects in lexical processing, such as differences in processing speeds between language-ambiguous words that overlap in form and/or meaning across languages and language-unique control words. Although initial studies concluded that lexical access may be selective (Gerard & Scarborough, 1989), a wealth of empirical studies have typically been interpreted as supporting the non-selective hypothesis. For instance, cognates — words that share both form and meaning between languages — show processing advantages, a phenomenon referred to as the *cognate facilitation effect* (e.g., Costa et al., 2000; Dijkstra et al., 1999).

While this chapter does not focus on cognates, it is important to note that the exact definition of a cognate is debated. In the psychology of language, cognates are usually defined as words that share both form and meaning between languages. However, their form overlap may be orthographic, phonological, or both. Furthermore, the degree of form overlap can be either identical, with full form overlap (e.g., *film* in English and Dutch), or non-identical, with partial overlap (e.g., *soup* in English and *soep* Dutch). The similarity between cognates can be quantified in various ways, such as through human similarity ratings or string metrics like Levenshtein distance (see e.g., Roembke et al., 2024, for a review). While orthographic cognates are easier to identify due to consistent spelling conventions within a language and some overlap in alphabets between languages, defining phonological cognates can be more challenging, due to variation in sounds within and between languages, as well as individual speaker differences.

Similarly, evidence suggests that bilinguals may automatically activate native language (L1) translations when reading in their second language (L2) (Elston-Güttler, Paulmann, & Kotz, 2005; Thierry & Wu, 2007). As a result, most models of bilingual word recognition (Dijkstra & van Heuven, 1998, 2002; Dijkstra et al., 2019) assume *non-selective* activation across languages. Yet, the mechanisms driving the effects are still a topic of discussion. One particularly debated question is whether the effects demonstrate non-selectivity with regard to language activation, or whether other factors, such as co-activation during learning or language exposure, could explain the phenomena.

Although non-selective activation is the orthodox explanation for cross-linguistic effects, more recent hypotheses propose a more dynamic and flexible approach to selectivity in bilingual language processing (e.g., Costa et al., 2017; Hoversten & Traxler, 2020). For example, an alternative explanation for these effects is that during learning, the organisation of the native mental lexicon carries over to the new language (Costa et al., 2017). Costa et al. (2019) argue that the phenomena indicating non-selective activation may not always occur, for instance in highly proficient bilinguals. They call for a new, ‘dynamic and flexible’ understanding of the organisation of the bilingual lexicons (Costa et al., 2019, p. 4), and their account has sparked a lively debate on bilingual parallel activation (see e.g., Oppenheim et al., 2018; described in detail in Chapter 2). As we will see in this chapter, evidence also suggests that bilinguals may initially behave like monolinguals in contexts where only one of their languages is relevant, until input signals the relevance of their other language. For

example, studies such as Altarriba et al. (1996), showing that bilinguals slow down reading of code-switched words, indicate that it is possible that bilinguals generate expectations of the language of the upcoming input based on the context. Other factors such as semantic constraints, language context, and proficiency have also been shown to modulate the cross-linguistic effects that are often interpreted as evidence of non-selective lexical access (e.g., Elston-Güttler, Gunter, & Kotz, 2005; Lauro & Schwartz, 2017; Mulder et al., 2018), supporting the idea that bilingual processing is adaptive and context-dependent.

In this thesis, I focus on the cognate facilitation effect in non-native language comprehension to explore to what extent it demonstrates non-selective activation during word recognition. Cognate facilitation has been one of the most widely studied cross-linguistic effects and has often been interpreted as evidence for non-selective theories of bilingual word recognition and lexical access. I re-examine cognate effects in light of learning-based hypotheses, asking to what extent these effects can be explained by learning. Additionally, I use cognates to investigate whether predictive processing in an L2 is non-selective, or whether top-down influences, such as sentence context, can constrain lexical activation to become non-selective. With this research, I show that the effect can, in principle, be explained by learning, and that cognate effects by themselves do not demonstrate language non-selective activation. In this chapter, I review evidence from other cross-linguistic effects in light of learning-based hypotheses and argue that, like the cognate evidence, which is examined separately in Chapter 2, these effects also point to a need to reassess the role of selectivity in bilingual word recognition.

## **1.2 Language Selectivity in Bilingual Word Recognition: Models and Theoretical Perspectives**

How are humans able to convert a string of letters written on a page, or a stream of sounds, to a meaningful unit of language? This is the process of word recognition, which involves the decoding of orthographic or phonological input and matching it to a corresponding representation stored in memory, so that the word can be integrated within the context it appears in (Cottrell, 1988). These representations are assumed to be stored in the mental lexicon, a term used to describe how lexical knowledge is stored in the brain. The mental lexicon can be thought of as a database containing lexical information about the orthographic or phonological forms, morphosyntax, and meaning

of words. For example, for anyone who knows the English word *cat*, it is assumed that the mental lexicon consists of representations which contain information about the semantic concept of a cat, the letters or sounds used to convey this concept in language, as well as the morphosyntactic rules governing the use of the word, such as adding an *-s* at the end would entail more than one cat, or that it can be an object or a subject in a sentence, but not the verb.

The retrieval and activation of words from the mental lexicon is called lexical access, which is modality independent and used to describe the retrieval process in both comprehension and production. In word recognition, it is the process where input information activates matching representations in the lexicon. To give an example, if you encounter the word *cat*, lexical access occurs between the decoding of the string of letters (c, a, t) or the stream of sounds (/k/, /æ/, /t/) and integrating its meaning ('cat') into context.

While a comprehensive review of word recognition and its models in the monolingual domain is beyond the scope of this thesis, it is worth noting briefly that the most dominant views are based on the assumption of *interactive activation*, where activation of lexical representations flows through the mental lexicon through a process of spreading activation (e.g., McClelland & Rumelhart, 1981). This means that representations that are in some way related to the input string in form or semantics may receive some activation. For instance, upon encountering the word *cat*, the input string may also activate representations for words related in form, such as *car*, or words related in meaning, like *dog*.

Evidence for spreading activation comes from findings of form-priming and semantic priming, where recognition of words is faster if they are preceded by a word that is related in form or meaning (Forster, 1987; Kreher et al., 2006; D. E. Meyer & Schvaneveldt, 1971; Neely, 1990). Findings from ambiguity resolution further suggest that lexical representations are activated in parallel during the recognition process. In single-word processing, an ambiguity advantage has been found for words with related senses (e.g., *run*), while distinct meanings (e.g., *bat*) lead to a disadvantage in processing (Rodd et al., 2002; see also Rodd, 2018, for a review). Additionally, findings from sentence reading studies suggest that people consider all meanings of an ambiguous word, although there is some evidence that a biasing sentence context can constrain this activation (e.g., Duffy et al., 1988; C. Martin et al., 1999; Onifer & Swinney, 1981; Rayner & Duffy, 1986; Swinney, 1979).

In a bilingual context, word recognition becomes particularly intriguing as it involves

navigating between representations in two (or more) languages. How are bilinguals able to keep their languages separate yet understand either one with little effort at any given time? For bilinguals, the speed and accuracy of word recognition can be influenced by within-language factors, such as word frequency, but also by between-language factors, such as whether a word's written form exists in only one or both of a bilingual's languages (e.g., Diependaele et al., 2013; Dijkstra, van Jaarsveld, & ten Brinke, 1998; Dijkstra et al., 2010). This suggests that the process involves some kind of interaction between lexical representations across languages. However, as we will see below, the nature of this interaction is an ongoing debate in the literature, with many possibilities for how connections may operate and emerge within the bilingual mental lexicon.

The issue of whether bilingual word recognition is non-selective has been explored through different experimental paradigms, utilising classic reaction time experiments, such as lexical decision, to more temporally precise techniques, such as eye-tracking and Event-Related Potential (ERP) studies. In these experiments, an important factor is whether participants are processing words in a one-language or two-language context. In a one-language context, where only one language is relevant, bilinguals may show more selective lexical access. In contrast, two-language contexts — where both languages are relevant — may result in non-selective activation. Thus, the experimental context plays a crucial role for non-selective activation, and according to de Groot et al. (2000), 'support for the selective-access view comes primarily from studies that presented paragraphs or sentences in either a unilingual form or in a mixed ("code-switched") form' (p. 422), citing works such as Kolers (1966), Macnamara and Kushnir (1971), and Soares and Grosjean (1984). Similarly to the study from Altarriba et al. (1996) discussed above, these studies found processing difficulties with mixed stimuli, which has been interpreted as evidence for an automatic language-switching mechanism that 'directs the incoming information to the appropriate linguistic system' (de Groot et al., 2000, p. 422).

As mentioned in Section 1.1, in addition to evidence from code-switching studies, much of the current evidence on bilingual word recognition comes from the processing of words that are form-related between languages, or the translations of words that are form-related within a language, examined in both one- and two-language contexts. These types of cross-linguistic effects are more likely to occur in two-language contexts (e.g., Poort & Rodd, 2017; Wu & Thierry, 2010). However, this thesis is focused on processing in one-language contexts, which allows for a clearer comparison to monolingual processing, enabling insights into whether bilingual language processing

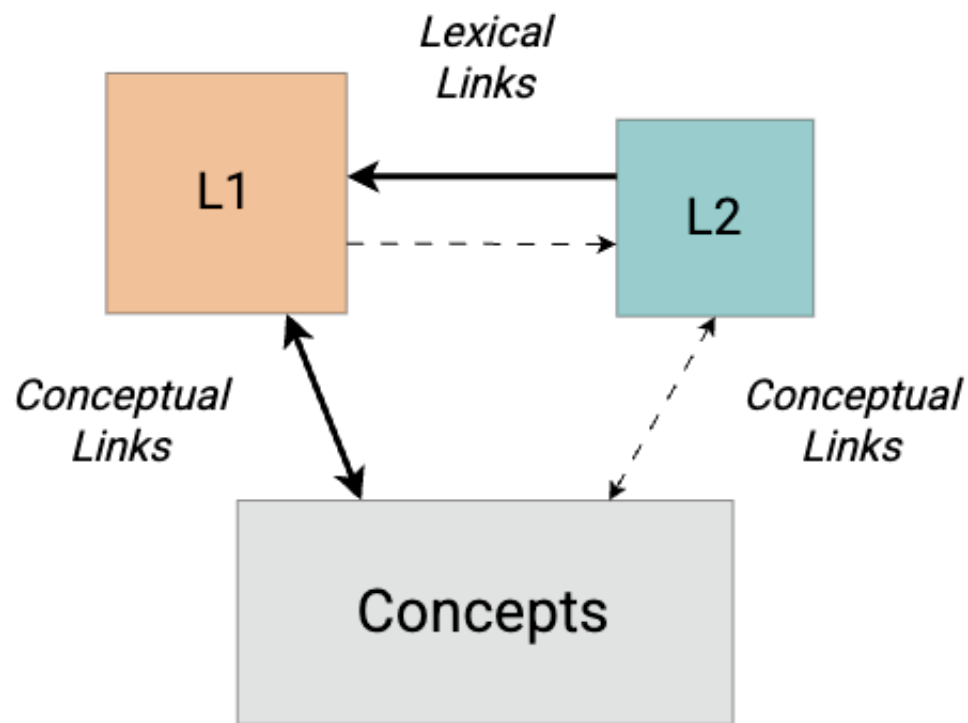
resembles that of monolinguals when only one language is activated. Therefore, unless otherwise specified, the experiments discussed in this thesis concern L2 processing in one-language contexts.

In what follows, I review the current evidence for and against language selectivity in bilingual word recognition. First, I present the evidence and models that led to the development of models of bilingual word recognition. I then evaluate empirical work conducted to test the models in question, with a particular focus on studies that find evidence for selective activation. I look at the contribution of contextual and lexical cues to language selective activation in lexical access, and additionally what speaker characteristics may restrict bilingual language activation to be selective. This chapter is focused on lexical cross-language effects in comprehension, with the exception of cognate effects, which are extensively discussed in Chapter 2.

### **1.2.1 Models of Bilingual Word Recognition**

Theories assuming parallel (i.e., non-selective) activation have the benefit of adhering to the principle of parsimony, as they are rooted in monolingual models of word recognition that assume interactive activation. If such models can account for the available empirical evidence with minimal modification when extended from a monolingual to a bilingual scenario, they reduce the risk of lacking explanatory adequacy, since the same mechanisms that explain monolingual processing also account for bilingual phenomena without the addition of ad hoc assumptions or mechanisms that ‘serve no other purpose than to make the model display the desired behavior’ (Frank, 2021, p. 202). However, as we will see in this chapter, simply applying assumptions from the monolingual domain to the bilingual case brings forth complications. In particular, one problem which does not occur in monolingual processing is how language membership of words can influence word recognition.

One of the earliest models to address bilingual lexical processing is the Revised Hierarchical Model (RHM), which I briefly describe below. Then, I will first present some of the empirical evidence that led to the proposal of the most influential models of bilingual word recognition, the Bilingual Interactive Activation (BIA) model, along with the model’s assumptions, before I discuss subsequent experiments testing its assumptions, leading to its extension, the BIA+ model.



**Figure 1.1.** The Revised Hierarchical Model (RHM). Thickness of arrows represents connection strength. Figure adapted from Kroll and Stewart (1994).

### 1.2.1.1 The Revised Hierarchical Model

The RHM (Kroll & Stewart, 1994) is a verbal model of late L2 word learning. While primarily a model of word production (Kroll et al., 2010), the RHM has been widely applied to bilingual word recognition as it provides a framework for understanding how connections between representations in the bilingual mental lexicon are established and develop with increased L2 proficiency. As shown in Figure 1.1, the model includes representations for words on the lexical level (word form, indicated by the squares in Figure 1.1), which are organised into separate lexicons for each language, and the conceptual level (word meaning, indicated by the rectangle in Figure 1.1), which is shared across languages. According to the RHM, L2 words are initially linked to the lexical representations of their corresponding L1 translation equivalents (the *lexical links* in Figure 1.1), which are directly linked to their conceptual representations (the *conceptual links* in Figure 1.1). With increased L2 proficiency, direct links between L2 lexical representations and their concepts develop. These connection strengths are asymmetrical, with stronger lexical links from the L2 to the L1 than vice versa, and stronger links between the L1 and concepts than between the L2 and concepts.

To test the predictions of the RHM, Kroll and Stewart (1994) conducted a two-

language) experiment with Dutch–English bilinguals, where they translated and named words presented in a list with words from the same semantic category (e.g., *dress, suit, shoes*) or a randomised list (*orange, lion, ambulance*). Translation from the L2 to the L1 was faster than from the L1 to the L2, and it was further not affected by category interference (i.e., interference caused by the translated words being in the same semantic category). The authors conclude that this is in line with the assumptions of the RHM of asymmetric connections: L2–L1 translation occurs through the lexical links, and does not require mediation through the conceptual level, as is the case in L1–L2 translation. Furthermore, naming was faster in the L1 than the L2, and this was not affected by semantic category, supporting the assumption of weaker links between the lexical and conceptual levels in the L2. Kroll and Stewart (1994) also cite evidence from (two-language) cross-linguistic semantic priming studies (e.g., Keatley et al., 1994) that show asymmetric priming patterns (stronger priming from L1 to L2 than vice versa) as support for the model. These are in line with RHM’s predictions that words from the L1 should prime target words from the L2 more often than L2 primes should prime L1 targets because they are more likely to activate concepts.

### **1.2.1.2 The Bilingual Interactive Activation Model**

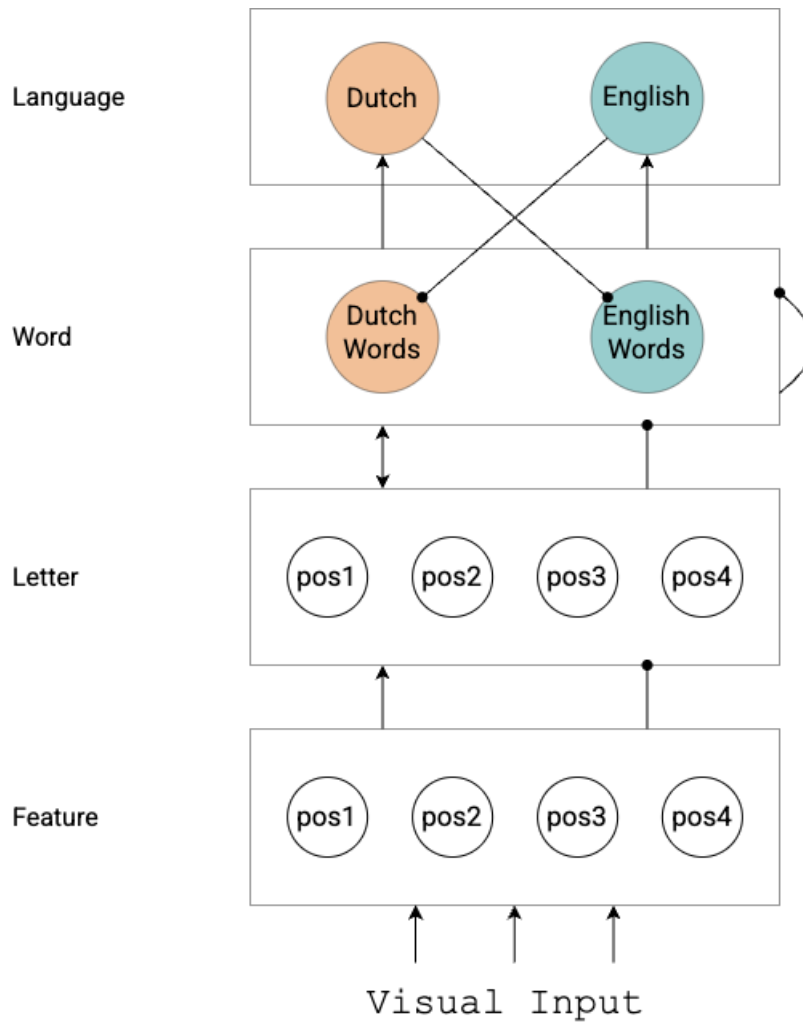
In a series of experiments designed to inform and test the BIA and later the BIA+ models of bilingual word recognition, Dijkstra and colleagues extensively examined cross-linguistic effects in single word processing, such as cognate and interlingual homograph effects, as well as how language mixing and task demands modulate these effects. Below, I briefly summarise these studies, focusing on evaluating the evidence for non-selective activation leading up to the development of the BIA model, and then outline the assumptions of the BIA model.

Perhaps the most influential evidence supporting non-selective activation in the bilingual word recognition system comes from the finding that cross-linguistically similar words can speed up or slow down bilingual word recognition. One line of evidence comes from studies examining the effects of cross-language neighbours. A lexical neighbour is a word that differs from another word by one letter or sound (by substitution, deletion, or addition), and a word can have many or few neighbours. For instance, *car* is a within-language orthographic neighbour of the English word *cat*, while the Dutch word *vat* (‘barrel’) is one of its cross-language orthographic neighbours. In a series of progressive demasking and lexical decision experiments, van Heuven et al. (1998) found inhibition from cross-language orthographic neighbours in Dutch–English

bilinguals. This effect occurred regardless of whether the stimuli were presented in separate or mixed blocks for each language and was also present in an English-only lexical decision task.

Interlingual homographs have along with cognates been extensively studied to better understand cross-linguistic influences in bilingual lexical access. In contrast to cognates, interlingual homographs overlap only in their form, but not in meaning in a language-pair (such as *coin*, meaning ‘corner’ in French). With the same population, Dijkstra, van Jaarsveld, and ten Brinke (1998) found facilitation for cognates but no effects for interlingual homographs relative to control words in an English lexical decision task (Experiment 1). However, when Dutch fillers were included in the same task, they observed inhibition that depended on the frequency of the homograph’s Dutch reading (e.g., the homograph *boom*, meaning ‘tree’ in Dutch, which has a high word frequency in Dutch but a low frequency in English). In a generalised lexical decision task (Experiment 3), however, they found facilitation relative to English control words. The authors conclude that task demands and stimulus language membership can lead to more language selective or non-selective patterns. They hypothesise that the null effects for interlingual homographs in the single-language task arise because the English lexicon inhibits Dutch words, while cognates were facilitated because their Dutch reading was activated long ‘enough to contribute to semantic activation’ (p. 61). Comparing the results to the two-language experiments, they proposed that non-target language stimuli activate the non-target language in a bottom-up fashion, and this activation is not easily overridden by top-down sources, such as task demands.

These findings contributed to the assumptions of the BIA model (Dijkstra & van Heuven, 1998; Dijkstra, van Heuven, & Grainger, 1998; Grainger & Dijkstra, 1992), which is an algorithmic model of bilingual word recognition based on the monolingual Interactive Activation model (McClelland & Rumelhart, 1981). It combines bottom-up, non-selective processing, where letters activate words across languages in a shared lexicon, with top-down, language-specific processing in which language nodes inhibit words from the non-target language. The model takes a string of letters as input, with specific features at each letter position activating matching letters while inhibiting others (*feature* and *letter* levels in Figure 1.2). Activated letters send excitatory activation to words across languages with these letters in the corresponding positions, while all other words are inhibited (illustrated at the *word* level in Figure 1.2). This activation is modulated by the resting level activation of the individual word nodes, which is lower for L2 words than L1 words because L1 words have been encountered more often



**Figure 1.2.** The Bilingual Interactive Activation Model (BIA). Arrowheads represent excitatory connections, and inhibitory connections are represented by filled black circles. Figure adapted from van Heuven et al. (1998).

(van Heuven et al., 1998). Words across languages inhibit each other at the word level, and activated words send feedback activation to their constituent letters.

What makes the BIA model special is its language nodes, which provide both bottom-up and top-down control mechanisms, as well as a representational role of linking words to their respective languages (the language nodes are shown at the *language* level in Figure 1.2). Their activation indicates the level of activity within each lexicon. Bottom-up activation of the language nodes occurs automatically through lexical representations activating their respective language nodes, and further, through the language nodes' inhibition of lexical representations on the word level. Top-down activation, on the other hand, which can inhibit all non-target language representations, can occur if there is an

expectation that a word belongs to a specific language. For instance, the language nodes explain the differences in interlingual homograph processing observed by Dijkstra, van Jaarsveld, and ten Brinke (1998).

The BIA model has successfully simulated several empirical findings of cross-linguistic effects across different kinds of lexical decision tasks, such as interlingual homograph processing and within- and between-language neighbourhood effects in Dutch–English bilinguals (Dijkstra, Timmermans, & Schriefers, 2000; Dijkstra & van Heuven, 1998; Dijkstra, van Heuven, & Grainger, 1998; van Heuven et al., 1998), as well as (masked) orthographic priming in French–English bilinguals (Bijeljac-Babic et al., 1997; Dijkstra, van Heuven, & Grainger, 1998). However, these simulations required specific assumptions. For example, the simulations of interlingual homograph processing and neighbourhood effects relied on asymmetric top-down inhibition in the model, whereas the simulations of translation priming excluded top-down inhibition from the language nodes.

In subsequent experiments, Dijkstra et al. (1999) found that orthographic and semantic overlap facilitates processing, while phonological overlap inhibits processing in lexical decision and progressive demasking. Based on this replication of Dijkstra, van Jaarsveld, and ten Brinke (1998), Dijkstra et al. (1999) reinterpret the conclusion of Dijkstra, van Jaarsveld, and ten Brinke (1998) that language context can contribute to bottom-up inhibition, instead suggesting that interlingual homographs can be facilitated if phonological overlap is low. They hypothesise that the null result in Dijkstra, van Jaarsveld, and ten Brinke (1998) is the combined influence of facilitation from orthographic overlap and inhibition from phonological overlap. The combined findings from these two studies, in addition to the findings from e.g., Dijkstra, van Jaarsveld, and ten Brinke (1998) that word frequencies in each language contribute individually to the processing of interlingual homographs, suggested that interlingual homographs and cognates have two orthographic representations in the bilingual word recognition system, one for each language, and that the different levels of representations on the orthographic, semantic, and phonological levels can contribute differently to the word recognition process.

Later experiments brought more clarity to the non-linguistic and linguistic factors affecting word recognition. In Dijkstra, de Bruijn, et al. (2000), Dutch–English bilinguals performed a lexical decision task where they were informed about the occurrence of homographs and (Dutch) non-target language words, but unbeknownst to them, Dutch words were only introduced in the second block. Interestingly, inhibition

for interlingual homographs was only observed in the second block when non-target language words were introduced, in addition to a smaller and less robust inhibition of reaction times to English control words. Partially replicating the findings of Dijkstra, van Jaarsveld, and ten Brinke (1998), Dijkstra, de Bruijn, et al. (2000) suggest that language intermixing and participants' implicit expectations are more important to determining language mode than explicit instructions. They also rejected the hypothesis of Dijkstra, van Jaarsveld, and ten Brinke (1998) that the null effect for interlingual homographs could be attributed to relative language activation, proposing instead that the absence of effects in the first block may be due to context-sensitive adaptations of the participant's decision behaviour based on the stimulus list composition.

Further evidence from Dijkstra, Timmermans, and Schriefers (2000) and de Groot et al. (2000) suggests that participants cannot switch off the non-target language to optimise performance. For example, Dijkstra, Timmermans, and Schriefers (2000) examined interlingual homograph recognition in Dutch–English bilinguals performing language go/no-go tasks, which required participants to suppress the non-target language to optimise performance because they were instructed to respond only to target language words, while ignoring words in the non-target language. Here, recognition of a homograph was still influenced by the word frequency of its non-target language readings. This suggests that non-linguistic task demands cannot fully override the effects of stimulus list composition, but decision criteria can be adjusted to optimise responses.

Lemhöfer and Dijkstra (2004) replicated the findings of Dijkstra et al. (1999), observing cognate facilitation in both language-specific and generalised lexical decision tasks, and facilitation for orthographic interlingual homographs only in language-specific lexical decision. They propose that cognates and interlingual homographs have two representations, one for each language. Cognate facilitation is explained by feedback activation from the semantic level (as detailed in Chapter 2), whereas interlingual homographs are not facilitated due to the lack of semantic overlap. The facilitation of orthographic interlingual homographs in the single-language task is attributed to the fact that, in generalised lexical decision, the response can be based on the L1 reading of the homograph, which is usually available first. In contrast, in language-specific lexical decision, the language membership of the homograph needs to be verified, allowing time for the non-target language reading to affect response times.

Based on these findings, Dijkstra and van Heuven (2002) identified six limitations of the BIA model. It does not include phonological or semantic representations, it

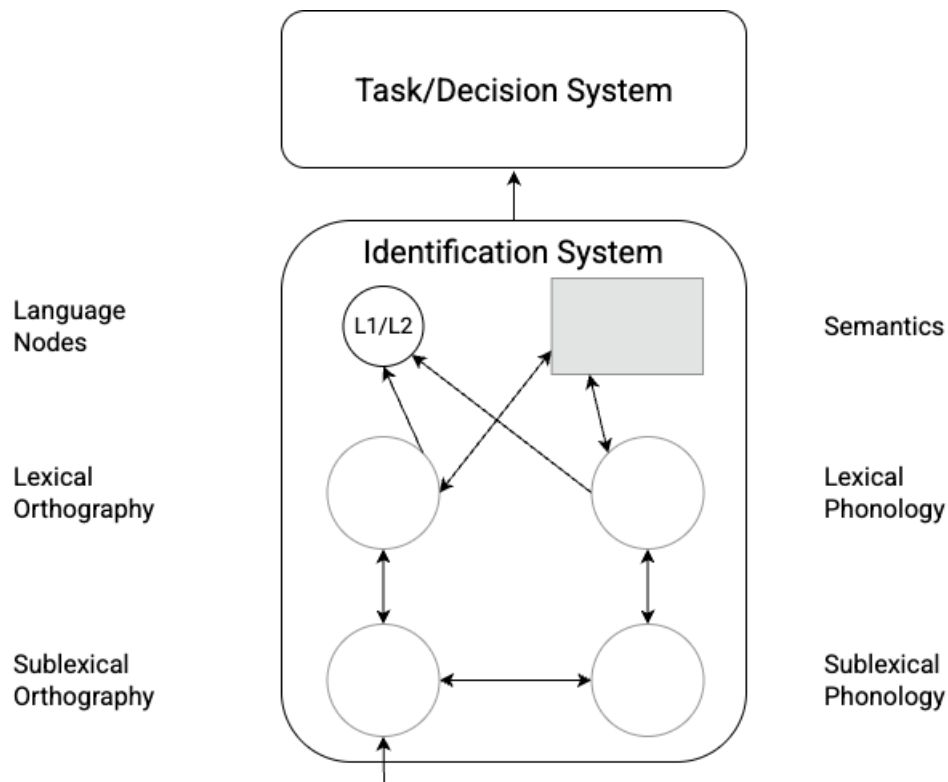
inadequately defines representations for cognates and interlingual homographs, and conflates the representational and functional roles of the language nodes. Additionally, it provides limited insight into the influence of linguistic and non-linguistic contexts, task-specific processes, and the interaction between word identification and task demands. To address these issues, they proposed an extended model, the BIA+, which offers a verbal analysis of the components required to overcome these limitations.

### 1.2.1.3 The Bilingual Interactive Activation+ Model

The BIA+ model (Dijkstra & van Heuven, 2002) is influenced by the Inhibitory Control model (Green, 1998), which outlines how bilinguals manage control over processing within their lexico-semantic system under various task conditions. Thus, the BIA+ model introduces a distinction between two partially independent components: the word identification system and a task/decision system (see Figure 1.3 for a visual representation). The word identification system is affected by linguistic context, such as sentence context, while the task/decision system is influenced by non-linguistic context, like stimulus list composition. Several modifications were made by Dijkstra and van Heuven (2002) to address the shortcomings of its predecessor, which I describe below.

In the BIA+ model, phonological and semantic representations are included in addition to orthographic representations, allowing for non-selective activation at all levels of the integrated lexicon, which arises at the sublexical and lexical orthographic levels (Dijkstra & van Heuven, 2002). This inclusion is based on evidence of cross-language effects at all three levels (Dijkstra et al., 1999, discussed above). Similarly to the BIA model, orthographic input activates matching orthographic representations, with activation strength dependent on both subjective frequency (which determines the resting level activation of the representations, with higher activation for L1 than L2 nodes) and degree of similarity between the input and representations (higher activation for more similar matches). This activation then flows to the corresponding phonological and semantic representations, where it is similarly influenced by subjective frequency.

A key assumption of the BIA+ model is the *temporal delay assumption*: L2 representations are activated more slowly than L1 representations due to differences in resting level activations. This delay leads to larger cross-linguistic effects from L1 to L2 than vice versa, particularly when task demands allow responses to faster codes (e.g., L1 orthographic codes), preventing slower codes (e.g., L2 codes) from influencing response times. This allows for a modulation of the contribution of codes to the



**Figure 1.3.** The Bilingual Interactive Activation+ Model (BIA+). Arrows represent flow of activation between representational pools. Figure adapted from Dijkstra and van Heuven (2002).

decision by ‘adapting temporal deadlines rather than by refiguring the task schema’ (Dijkstra & van Heuven, 2002, p. 183). The assumption is based on empirical findings of facilitation for cognates and interlingual homographs based on orthographic and semantic similarity, while phonological similarity causes inhibition (Dijkstra et al., 1999), whereas in generalised lexical decision, facilitation only occurred for cognates and not for interlingual homographs (Lemhöfer & Dijkstra, 2004). According to Dijkstra and van Heuven (2002), these results suggest that task demands can modulate the influence of lexical codes without changing activation patterns in the word identification system. When a task, such as single-language lexical decision, requires verification of the English language membership of the possible word candidates, the earlier availability of Dutch codes can affect the more slowly activated English codes. In tasks like generalised lexical decision, where such verification is not required, responses rely on the faster-available Dutch orthographic code, reducing cross-language influence.

Another significant change in the BIA+ model involves the representation of interlingual homographs, which now have two orthographic representations. Evidence

from mixed-language experiments from Dijkstra, van Jaarsveld, and ten Brinke (1998) suggests that the frequency of the L1 and L2 meanings influences inhibition and facilitation effects of interlingual homographs. Facilitation occurs when the most frequent reading of homographs is available first, and inhibition or null results arise from occasional access to their lower frequency readings, which may make the ‘resulting mean reaction time just somewhat faster than that of the high-frequency control’ (Dijkstra & van Heuven, 2002, p. 185). This explains both inhibition and facilitation for interlingual homographs in the model, which is in line with previous findings (Dijkstra, van Jaarsveld, & ten Brinke, 1998).

The most notable difference between the BIA and BIA+ models is the redefined role of the language nodes. In the BIA+ model, language nodes represent language membership within the word identification system but do not influence word activation (Dijkstra & van Heuven, 2002), and their activation is not affected by non-linguistic information outwith the word recognition system. Instead, non-linguistic effects are handled by a separate task/decision system, which modulates decision criteria without altering the word activation. This change is justified by evidence suggesting that information about language membership is not available early enough to affect word identification. For instance, in the language go/no-go task of Dijkstra, Timmermans, and Schriefers (2000) (of which the BIA model could account for accuracy but not reaction time patterns (Dijkstra & van Heuven, 1998, 2002)), interlingual homographs were wrongly classified as not belonging to the target language if the frequency of the non-target reading was high. The authors hypothesise that this may be because recognition of the non-target language meaning suppressed any further recognition of the homograph’s reading in the target language.

Non-linguistic factors, such as task expectations, influence the task/decision system, which modulates decision criteria independently of the word identification system. Dijkstra and van Heuven (2002) argue that there is ‘little pertinent evidence in favour of top-down inhibition of active lexical candidates on the basis of task demands or participant strategies’ (p. 188). As evidence, they cite the above-mentioned studies that found inhibition for interlingual homographs in mixed-language tasks (Dijkstra, Timmermans, & Schriefers, 2000; Dijkstra, van Jaarsveld, & ten Brinke, 1998) and from phonological overlap in English lexical decision (Dijkstra et al., 1999), suggesting that participants cannot suppress non-target language candidates during word recognition, even when doing so would optimise responses. Instead, inhibition arises from competition between lexical representations in both languages, suggesting that task demands (for example,

only English words being relevant) do not directly affect the word identification system.

Dijkstra and van Heuven (2002) discuss further evidence to support the separation of the word identification system and the task/decision system from studies which show stable responses to control items regardless of changes in task demands, such as which language is relevant or the stimulus list composition (e.g., Dijkstra, van Jaarsveld, & ten Brinke, 1998; van Heuven et al., 1998). While non-target language items in the stimulus lists could, in theory, slow responses to target language items by increasing non-target language activation, this is not observed. These findings are explained by *stimulus-response binding*, where the task/decision system specifies how activated representations are linked to responses (e.g., “yes” to only English words in an English lexical decision task or to both Dutch and English words in a generalised lexical decision task). This mechanism also accounts for mixed findings in interlingual homograph processing, where both null results and inhibition effects have been observed (e.g., de Groot et al., 2000; Dijkstra, de Bruijn, et al., 2000; Dijkstra, van Jaarsveld, & ten Brinke, 1998). According to the authors, these findings reflect small changes in the decision process rather than shifts in language activation within the word recognition system.

According to Dijkstra and van Heuven (2002), linguistic context, such as lexical, syntactic or semantic information, can influence the degree of language selectivity in the word identification system, though the exact mechanisms remain unclear, as in the BIA+ model language nodes cannot affect word activation. They argue that ‘language information does not provide strong selection constraints on bilingual word recognition’ but leave the possibility open that ‘sentence context can interact with the bilingual word identification process’ (p. 187).

Dijkstra and van Heuven (2002) acknowledge that the issue of how the BIA+ model develops over time and during learning needs to be addressed. Several researchers have highlighted the lack of learning mechanisms in the BIA+ model. For instance, Jacquet and French (2002) point out that the model’s excitatory and inhibitory connections are hand-coded rather than learned. Li (2002) notes that while the BIA+ model effectively simulates proficient bilinguals, it overlooks developmental aspects, such as how shifts between language-selective and non-selective access are affected by proficiency. Thomas (2002) emphasises the importance of adopting a developmental perspective in future models, focusing on how the system learns representations and adapts to solving the task at hand, rather than adapting model assumptions to fit empirical data. Additionally, Green (2002) discusses the influence of sublexical cues, such as language-specific letters and bigrams, in signalling language membership information and affecting word

recognition.

#### 1.2.1.4 Developmental Bilingual Interactive Activation Model

Grainger et al. (2010) presented a theoretical framework to incorporate how the BIA architecture, and specifically its control mechanisms, would emerge through L2 acquisition. This work was rationalised by the assumptions of the RHM that lexical representations in the L1 have stronger connections to the semantic concepts than to their corresponding translation equivalents in the L2, whereas lexical representations in the L2 have stronger (excitatory) connections to the representations of their corresponding translation equivalents in the L1 than to their conceptual representations. The authors point out that evidence from non-cognate translation priming in proficient bilinguals challenge this assumption: on one hand, translation priming from the L2 to the L1 is weaker or absent (e.g., Finkbeiner et al., 2004; Gollan et al., 1997) compared to translation priming from the L1 to the L2 (e.g., Gollan et al., 1997; Voga & Grainger, 2007), which suggests that lexical representations in the L2 do not have ‘strong excitatory connections with their L1 translation equivalent’ (Grainger et al., 2010, p. 275). On the other hand, Grainger et al. (2010) cite evidence showing masked non-cognate translation priming from the L2 to the L1 in highly proficient bilinguals (e.g., Basnight-Brown & Altarriba, 2007; Duñabeitia et al., 2010), which they, along with Grainger and Frenck-Mestre (1998) and Midgley et al. (2009), argue may reflect facilitated access to the shared semantic representations instead of direct connectivity between the L1 and L2 representations on the form level. Grainger et al. (2010) query how a system can transition from exhibiting excitatory connections between corresponding L1 and L2 lexical representations during the early stages of L2 vocabulary acquisition to not having these direct connections when L2 proficiency becomes moderate. They address this issue by proposing the Developmental Bilingual Interactive Activation (BIA-d) model.

The BIA-d is a unification of the RHM and the BIA model, and more specifically, it describes how connections change between L1 and L2 lexical representations such that the model goes from the initial RHM model to the BIA model. Initially, in adult L2 learning, as per the RHM, connections between translation equivalents develop through L2 exposure and strengthen (e.g., through Hebbian learning) with increased exposure, while direct connections develop between lexical representations in the L2 and their corresponding semantic representations (Kroll and Stewart, 1994, as cited in Grainger et al., 2010). Crucially, at a critical point of the development of L2 proficiency when

L2 processing becomes less effortful, lexical representations in the L2 integrate into ‘a single lateral inhibitory network for words from both languages, as in the BIA model’ which modifies the connections between them, while the direct connections between L2 representations and their semantic counterparts are strengthened further (Grainger et al., 2010, p. 275). Grainger et al. (2010) claim that this qualitative shift in the links between L1 and L2 form representations of translation equivalents arises from the need for enhanced control over L2 activation as L2 vocabulary becomes larger. In the BIA-d model, this control is implemented as the ability to globally inhibit non-target language lexical representations during processing, and it is performed by the language nodes.

The BIA-d is a dynamic modeling approach incorporating basic learning mechanisms from cognitive development. According to Grainger et al. (2010), these learning mechanisms could account for the development from excitatory connections between L1 and L2 translation equivalents to no such excitatory connections in L2 vocabulary acquisition. In the model’s initial state, a set of L1 (orthographic)<sup>1</sup> word forms are connected to distributed semantic representations through ‘mutually excitatory connections to certain semantic features’ (p. 277). Furthermore, the form representations of orthographically similar words that have no semantic features in common (e.g., *chain* and *chair*) are co-activated, but have mutually inhibitory connections as in the IA model (McClelland & Rumelhart, 1981).

In the BIA-d model, late L2 vocabulary classroom learning occurs in two overlapping phases, starting with supervised learning which gradually turns into unsupervised learning. The supervised learning phase consists of learning of new word forms in the L2 along with their L1 translation equivalents and the information that the word form is an L2 word. Here, the L1 and L2 form representations are co-activated along with their corresponding semantic representations and L2 language node. In the initial network training phase, the activation of the L1 translation equivalent’s word form representation, which also activates its corresponding semantic features (providing the meaning of the new L2 word form), is clamped at ‘some maximum value (for supervision)’ (p. 278), and a language node with low initial activation level (providing language membership information) is created. Through Hebbian learning, connections between the compatible co-activated representations, i.e., the L2 word form and the L1 translation equivalent, the corresponding semantic features, as well as the L2 language node are strengthened.

The unsupervised learning phase occurs when L2 word forms reach a critical

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<sup>1</sup>The model only has orthographic form representations, but the authors note that its principles also apply to spoken language learning.

activation level independently of the L1 translation equivalents, and the clamping mechanism is dropped. Hebbian learning continues strengthening the connections between L2 word forms, their semantic features, and the L2 language node, while the L2 language node begins to exert top-down inhibition to L1 translation equivalents. The inhibition is reinforced with increased activation of the L2 language node, resulting in a reduction of the strength of the excitatory connections between L2 and L1 word form representations. With increased exposure to L2 word forms, developmental changes include strengthened excitatory connections between L2 word forms and their semantic features as well as increased inhibitory connections from the L2 language node to L1 word forms, leading to a reduction of the excitatory connections between L2 and L1 word forms that were formed during the initial learning phase. For this, Grainger et al. (2010) cite evidence showing L1 inhibition in L2 acquisition (Levy et al., 2007; Linck et al., 2009). Additionally, inhibitory connections emerge between L2 word forms and orthographically similar words in both L2 and L1. The resulting network is equivalent to the BIA model with semantic representations.

### **1.3 Language Selectivity in Bilingual Word Recognition: Empirical Data**

Kroll et al. (2010) acknowledge that while models such as the BIA+ can account for visual word recognition in detail, it is necessary to consider mechanisms of developmental change in models of the bilingual lexicon that can account for changes in language selective activation, dominance shifts under immersion, and the role of inhibitory mechanisms that suggest that the continuous learning and use of an L2 may lead to dynamic changes in the strength of connections between words and concepts. As we will see in the discussion below, these aspects, among others, are important when assessing selectivity in bilingual word recognition.

So far, the evidence we have seen from the studies informing the BIA and BIA+ models suggests that single-word recognition in bilinguals is non-selective, when evidence from effects from cognates, interlingual homographs, and cross-language neighbourhood are considered. However, as we saw in Section 1.2.1, interlingual homograph effects do not always occur, which is explained by top-down inhibition from language nodes in the BIA model, and modulations of the response by the task/decision system in the BIA+ model. Likewise, as will become evident in Chapters 2–5, cognate facilitation

can be explained by other factors than the converging activation and semantic feedback assumed in the BIA+ model. This leaves us with cross-linguistic neighbourhood effects. Kroll et al. (2010) argue that the evidence for these effects is ‘arguably the most fragile data among the demonstrations for parallel activation’ (p. 2). I now move on to examining evidence from studies that have found evidence for non-selective activation, evaluating to what extent these actually suggest activation is non-selective, starting with experiments on cross-language neighbourhood effects.

### **1.3.1 Cross-Linguistic Neighbourhood Effects**

According to Grainger et al. (2010), the most convincing evidence in favour of non-selective activation is cross-language neighbourhood effects because these can be observed in a complete one-language context with no explicit activation of the irrelevant language. It is well established in the study of monolingual word recognition that (within-language) neighbours can influence word recognition: for instance, lexical decision times are facilitated for words that have more neighbours relative to words that have fewer neighbours (see e.g., Grainger, 1992, for a review), though there are cross-linguistic differences in the direction, and in some instances, the presence of effects, and further also their interpretation (see e.g., Perea, 2015, for a review). In bilingual word recognition, several studies have observed both facilitatory and inhibitory effects of cross-language neighbourhood size in both written (Bijeljac-Babic et al., 1997; Dirix et al., 2017; Midgley et al., 2008; van Heuven et al., 1998; Whitford & Joanisse, 2021; Whitford & Titone, 2019; Whitford et al., 2016) and spoken (Guediche et al., 2023) word recognition, as well as spoken word production (Hameau et al., 2021), with effects being observed even early in learning (Meade et al., 2018) and across different experimental paradigms.

Commissaire (2022) discuss previous findings of these effects from Bijeljac-Babic et al. (1997) and van Heuven et al. (1998) (discussed in Section 1.2.1), and note that although they have been considered a ‘major piece of evidence for the existence of lexical competition between lexical orthographic representations across languages, supporting the language non-selective lexical access hypothesis’ (p. 1095), more recent studies call in to question the robustness of the effects. As an example, she cites a replication attempt of van Heuven et al. (1998) (Mulder et al., 2018, Experiment 1), which found no inhibition from L1 neighbourhood size on L2 word recognition. Mulder et al. (2018) ascribed the absence of any effects to the higher L2 proficiency of

their bilingual group leading to increased within-language and reduced cross-language activation. In a replication of their study, Biedermann et al. (2024) found evidence of inhibition from L1 neighbours in L2 lexical decision in Dutch–English bilinguals with similar proficiency levels as Mulder et al. (2018), as well as less proficient Spanish–English bilinguals, although the effect was less robust in that the main effect was only significant in the Dutch–English bilinguals. Biedermann et al. (2024) propose that less proficient bilinguals were less able to inhibit cross-language lexical activation than the more proficient bilinguals.

The suggestion that proficiency may constrain cross-language activation finds support from an ERP study by Grossi et al. (2012), who found that the time course of cross-linguistic neighbourhood effects in (two-language; each language presented in separate blocks) semantic categorisation was different between early and late English–Welsh bilinguals, with effects for late bilinguals occurring later than for early bilinguals, who also displayed weaker effects. The authors conclude that learning experience may modulate non-selective activation, which should be taken into account by bilingual word recognition models, such as the BIA+ model.

Further findings from Commissaire et al. (2019) in French–English bilinguals suggest that also orthographic markedness, or in other words, information about language membership from sublexical cues, such as bigram frequency or language-specific letters (as previously discussed in Section 1.2.1), could explain inconsistent results of cross-language neighbourhood effects. With an L2 English lexical decision task, they found no effects from cross-language neighbourhood in French–English bilinguals when controlling for orthographic markedness, i.e., whether or not the stimuli contained legal bigrams in the L1.

Between-language neighbourhood effects have also been investigated in reading. Here, the effects tend to change direction and become facilitative. For instance, Dirix et al. (2017) analysed a bilingual eye-tracking corpus consisting of Dutch–English bilinguals' L1 and L2 reading times of a novel (Cop et al., 2017). In L2 reading, L1 neighbourhood density showed a significant main effect for single fixation durations and total reading times, with a facilitative interaction between neighbourhood density and word length (longer words were facilitated). Similar facilitatory effects for late eye-tracking measures were found by Whitford and Titone (2019) and Whitford et al. (2016) with French–English bilinguals.

Taken together, the evidence from studies on cross-language neighbourhood effects may appear inconsistent. Firstly, the effects are modulated by L2 proficiency (Bieder-

mann et al., 2024; Mulder et al., 2018), which reiterates the need for models such as the BIA+ model to explain how, over the course of L2 learning, activation can change from being more non-selective to being more selective, as per Kroll et al. (2010) and Li (2002). Second, based on the findings from Commissaire (2022) and Commissaire et al. (2019) that orthographic markedness explains these effects in isolated word recognition, future research should investigate whether the effects are as robust in L2 reading if markedness is taken into account. If this is not the case, cross-language orthographic neighbourhood effects may not be as indicative of non-selective access as previously thought, which should prompt us to reconsider assumptions of models like the BIA+, in line with Green (2002). I will return to discuss the roles of both proficiency and sublexical cues for constraining activation in word recognition, but first, I discuss a line of studies that constitute some of the ‘best known evidence’ (Costa et al., 2017, p. 1631) for non-selective activation, and I present an alternative interpretation of these findings from Costa et al. (2017).

### **1.3.2 Activation of Translation Equivalents**

In an ERP study by Thierry and Wu (2007), Chinese–English bilinguals performed a semantic relatedness task with English word pairs. These pairs were either related in form in their Chinese translations (*train: huo che – ham: huo tui*), or unrelated. The study found a reduced N400 amplitude for pairs with form-related L1 translations, regardless of semantic relatedness. The pattern was absent in an English monolingual control group, but was observed in Chinese monolinguals presented with the same stimuli in Chinese, who also exhibited behavioural effects in reaction times and accuracy. The authors interpreted the results as indicating unconscious and automatic activation of L1 translation equivalents during L2 comprehension.

Using the same semantic relatedness paradigm, Morford et al. (2011) replicated the findings of Thierry and Wu (2007) with deaf bilinguals whose L1 was American Sign Language (ASL) and who were highly proficient in L2 English. They point out that these findings go against the assumptions of models of L2 lexical development, such as the RHM (Kroll & Stewart, 1994), which assume that bilinguals more proficient in the L2 can access L2 word meanings without accessing the L1. They discuss the possibility that the ‘relatively long’ stimulus onset asynchronies (SOAs) of their and Thierry and Wu’s experiments could have given the participants additional time to access the L1 translation *after* retrieving the meaning of the L2 word (see also Kroll

et al., 2010). They cite evidence from a translation recognition task from Guo et al. (2012), where proficient Chinese–English bilinguals judged whether L1 words were correct translations of L2 words that were related in form (e.g., English *sugar* was paired with the Chinese word for *pond*, both pronounced and written similarly in Chinese) or meaning (e.g., English *needle* was paired with the Chinese word for *thread*) on incorrect trials. Participants were sensitive to the meaning and form of translations when the SOA was long (750 ms), while they only showed sensitivity to the meaning when the SOA was short (300 ms), with form effects arising later. Guo et al. concluded that access to the L1 translation occurred after access to the meaning of the L2 word. Morford et al. suggest that their results, as well as those of Thierry and Wu may be reduced or eliminated if the SOA is reduced.

Morford et al. (2011) also propose that the observed effect might reflect the learning experience of the participants: if signs and their English translations were presented together, this leads to co-activation between the languages, which can persist even after full L2 proficiency is reached. According to the authors, it is possible that the observed results do not demonstrate cross-language effects, but rather ‘a direct mapping of English orthography to ASL phonology could be construed as a within-language mapping of complex visual (i.e., not phonetic, and not English-specific) orthographic patterns to ASL phonology.’ (p. 290, Footnote 3).

A similar assumption of co-activation during learning is the explanation of Costa et al. (2017) for these results. As mentioned in Section 1.1, Costa et al. challenge the assumption that bilingual lexical processing always involves cross-language co-activation. Instead, they propose a learning-based account, where the structure of L1 lexical items carries over to the L2 during acquisition through the process of spreading activation and Hebbian learning. According to this account, associations formed during learning can explain cross-language effects without requiring non-selective activation.

They reinterpret the findings of Thierry and Wu (2007) by suggesting that the formal relationship between the Chinese translations might influence how their L2 counterparts become represented in the mental lexicon: upon learning the word *train*, its translation equivalent *huo che* becomes activated through their semantic relationship. Through spreading activation, *huo tui* would become activated through their phonological relationship, leading to the activation of its translation *ham*. Costa et al. (2017) posit that because *train* and *ham* are co-activated ‘in close temporal proximity, it is reasonable to assume that they should develop a connection’ (p. 1633).

To support their theory, Costa et al. (2017) implemented a computational model

trained on two toy languages (L1 Chinese and L2 English) consisting of six words (the English words *train*, *ham*, *apple* and their Chinese translation equivalents *huo che*, *huo tui*, *pin guo*). At the beginning of learning, only the L1 form-related words *huo che* and *huo tui* had a functional connection. The presentation of L2 words (e.g., *train*) elicited an excitatory activation of its L1 translation equivalent (e.g., *huo che*), simulating non-selective activation, which then spread to representations that had connection strengths higher than 0 (e.g., *huo tui*). Assuming a Hebbian learning mechanism, connections between representations strengthen when they are co-activated. For instance, as a Chinese speaker learns English, the connection between the representations of the Chinese word *huo che* and its English translation *train* grows stronger due to their shared meaning, which in turn results in spreading activation, allowing the activity of one lexical representation to activate related representations. Through this process, connections also form between seemingly unrelated words, such as *train* and *ham*, when *train* activates both *huo che* but also *huo tui*, which activates *ham*. Repeated co-activation of these representations during learning (which may diminish over time with increased proficiency (Costa et al., 2017, 2019)) increases their functional connectivity, even though they are neither semantically nor phonologically related.

The simulations of Costa et al. (2017) show that during and after training, *train* increasingly activates the unrelated word *ham*. Importantly, this persisted even after L1 representations were removed from the model, illustrating how learning-induced interactions between representations can account for the findings of Thierry and Wu (2007) without invoking on-line cross-language activation.

Costa et al. also discuss findings from Marian and Spivey (2003), which have been argued to support the non-selective activation view, from a learning perspective. In a visual world eye-tracking study, Russian–English bilinguals were presented with four objects (e.g., a shark, a balloon, a horse, and a napkin) and asked to “pick up the shark”. One of the objects (e.g., balloon – *sharik* in Russian) was a cross-linguistic phonological distractor object of the target, as the two names overlap in phonology. Results showed that participants looked more at the distractor than unrelated objects, suggesting that phonologically similar items are activated in parallel and compete between languages.

In Costa et al. (2017), the effect is explained by co-activation during learning: when learning English words such as *shark*, L1 Russian learners co-activate *sharik* due to the phonological overlap, which in turn activates *balloon*. Thus, *shark* and *balloon* may end up having related representations in L2 English, and can be co-activated without the assumption that L1 representations are activated non-selectively on-line. Additionally,

it could be that the objects themselves elicit activation of L1 names at some point after being presented to the participants. Marian and Spivey do not specify how long the participants viewed the objects, or when the instructions to pick up the target were given. As a result, it remains unclear whether the observed effect arose solely from hearing the L2 target word.

In another study investigating the activation of L1 translation equivalents in L2 comprehension, Elston-Güttler, Paulmann, and Kotz (2005) examined the competing activation of L1 homonym translations (e.g., L1 German: *Kiefer* – meaning ‘pine’ and ‘jaw’ in L2 English) in German–English bilinguals using ERP and behavioural measures. In one experiment, participants performed a lexical decision task on target words that were the English translation of one of the homonym meanings (e.g., *pine*), where the target was preceded by a related prime which was the other translation of the L1 homonym (e.g., *jaw*), or an unrelated prime (e.g., *teeth* – German: *Zähne*). For high-proficiency participants, related primes slowed reaction times only when the target was the translation of the dominant meaning of the homonym, but no significant ERP effects were observed. Low-proficiency participants exhibited a less negative N200 (i.e., reflecting ease of processing during the early stages of lexical access) for related primes, but without corresponding reaction time effects. Both groups elicited significantly more errors for related than unrelated targets.

In a follow-up experiment, the primes were embedded in sentences with the target immediately following the sentence (e.g., *The sticky candy stuck together his jaw – PINE/TEETH*). Targets related to the prime elicited slower reaction times and a more negative N200 (i.e., reflecting difficulty of processing) in low-proficiency participants, but no effects in high-proficiency participants. These null effects in high-proficiency bilinguals were similar to those of an English monolingual control group. Elston-Güttler, Paulmann, and Kotz (2005) interpreted their findings within the framework of the BIA+ model (Dijkstra & van Heuven, 2002) and the RHM (Kroll & Stewart, 1994). They propose that higher proficiency allows bilinguals to use semantic context and regulate tasks more effectively. However, they caution that this does not imply selective access and that ‘presumably high and low learners operate in a similar system’ (p. 1605). Instead, they suggest that constraints from language proficiency, language mode, and semantic context can modulate the system to such an extent that influences from the L1 are not detectable, resulting in behavioural and electrophysiological effects comparable to those of native speakers. They hypothesise that this modulation could occur through the task/decision system of the BIA+ model, or through top-down activation of the

language nodes in the BIA model.

Finally, Elston-Güttler, Paulmann, and Kotz (2005) hypothesise that cross-language activation occurs at different levels of lexical access. The N200, reflecting processing at the lexical level (orthographic processing and/or response inhibition), suggests that interference (or facilitation as in Experiment 1) originates at this level. In contrast, the absence of N400 effects aligns with the RHM's assumption that proficient bilinguals have acquired direct mappings between form and meaning of L2 words, whereas less proficient participants activate L2 words via an L1 translation link at the lexical level. However, the data complicates this conclusion: whereas high-proficiency participants exhibited an inhibitory effect in reaction times but no ERP effects, lower-proficiency participants showed ERP effects without corresponding behavioural effects. If high-proficiency learners have direct links, why would reaction time inhibition from related primes still occur?

One potential explanation, from a learning perspective, is that translation ambiguous words could be more difficult to learn because learners may incorrectly assume the wrong meaning of L2 translations of homonyms, thereby establishing links to incorrect (L1) meanings. For example, if L2 learners are taught that the L2 word *jaw* corresponds to *Kiefer* in the L1 without explicit disambiguation, they might mistakenly associate it with the meaning 'pine' instead of 'jaw', or access the correct meaning but find it harder to do so. An alternative explanation is based on Costa et al. (2017)'s interpretation of the data from Thierry and Wu (2007). They propose that words with related forms in the L1 become linked in the L2 through mechanisms like Hebbian learning and co-activation during learning. According to this view, connections between L1 homonyms may transfer to the L2 during learning, and remain co-activated within the L2 during processing. This could explain how 'pine' and 'jaw' might become linked and affect each other during processing in the L2 English for German–English bilinguals.

This explanation aligns with Degani et al. (2011), who hypothesise that Hebbian principles of co-activation establish associative connections between the unrelated meanings and translations of a translation ambiguous word. Although their account primarily addresses facilitation from translation ambiguous words in priming, more recent findings from Jouravlev and Jared (2020) lend additional support. Their study observed ERP translation ambiguity priming effects (larger P200 and reduced N400) in Russian–English bilinguals, with facilitation for L1 prime-target pairs when they had the same L2 translation with two distinct meanings and forms in the L1 (e.g., *kora* and *layat* – 'bark of tree' and 'to bark'), although behavioural effects (faster reaction times)

only arose when the pairs were conceptually identical (e.g., *osheinik* and *homut* – ‘dog collar’ and ‘horse collar’). No effects were observed in a monolingual control group, apart from the effects of conceptual relatedness. Jouravlev and Jared conclude that their data is compatible with the Hebbian-learning accounts of both Degani et al. (2011) and Costa et al. (2017).

To investigate whether L1 translations interfere with L2 processing or whether independent form-meaning mappings can be established by bilinguals, Elston-Güttler and Williams (2008) examined the influence of L1 polysemy on interpretation during L2 English sentence reading. L1 polysemy occurs when a single L1 word has multiple related meanings that correspond to distinct words in the L2 (like German *Blase*, which can mean both ‘blister’ and ‘bubble’ in English). Highly proficient German–English bilinguals performed a semantic anomaly task, judging whether a target word was an acceptable completion of a sentence. Sentences were constructed so that the context aligned with one L1 meaning of the target word, while the actual target was the English translation equivalent of the incongruous L1 meaning (e.g., *His shoes were uncomfortable due to a bubble.*). Participants made more errors and exhibited longer reaction times for these sentences compared to control sentences where neither L1 meaning fit the context (e.g., *She was very hungry because of a bubble.*) and compared to native English speakers. For verbs, bilinguals showed inhibition in both highly related and moderately related conditions, whereas nouns elicited stronger inhibition in the highly related compared to moderately related condition.

The study provides support for the idea that L1 lexicalisation patterns influence semantic processing in the L2, with different effects for nouns and verbs. Elston-Güttler and Williams attribute these differences to different processing routes. They suggest that the degree of conceptual overlap between word types plays a role, with nouns having more conceptual overlap than verbs because they share more features at the conceptual level (van Hell & de Groot, 1998). Polysemous verbs (e.g., *scrape*) activate their L1 translation equivalents (e.g., *kratzen*), which in turn activate related L2 words (e.g., *scratch*), indicating interference through lexical-level translation links. Because verbs share fewer conceptual features than nouns, their meanings are less likely to be mediated conceptually (van Hell & de Groot, 1998), and therefore, L2 learners may process verbs via an L2–L1 lexical link, rather than a direct form-meaning route. Polysemous nouns (e.g., *bag*), on the other hand, activate L1 conceptual information either indirectly through lexical-level connections or directly from L2 words. According to the authors, the interference observed in bilinguals for nouns is more likely driven

by indirect activation, as evidenced by the stronger effects for bilinguals compared to native speakers. They align their findings with the RHM (Kroll & Stewart, 1994), which assumes stronger L2–L1 lexical links than L1–L2 links during early stages of L2 learning. These links can continue to affect L2 processing even as more direct connections between L2 words and concepts develops with increased proficiency.

While Elston-Güttler and Williams's (2008) findings are interesting, they do not necessarily reflect automatic activation of L1 translations during *on-line* processing. The semantic anomaly task requires an overt response, which might involve post-lexical processes rather than purely lexical access. The authors briefly acknowledge this limitation, noting on p. 184 that the decision task could reflect contamination from explicit declarative knowledge. Moreover, reaction time and error patterns likely reflect processes beyond lexical access, such as integrating the target word's meaning within the sentence context. This interpretation aligns with evidence suggesting that task demands, such as the need for an overt response, modulate cognate processing in sentence contexts (Lauro & Schwartz, 2017). The larger interference effect in bilinguals could then reflect more difficulty rejecting the sentence because the L1 meaning was accessed *after* lexical access was completed, when the initially accessed L2 meaning did not make sense within the given context. I will return to discuss further evidence that supports this suggestion after introducing more recent research on interlingual homograph processing.

### 1.3.3 Processing of Interlingual Homographs

Although cognate processing in general is facilitated in visual word recognition, processing effects of interlingual homographs are less clear-cut even in single-language tasks, with observations of inhibition, meaning slower recognition times than for control words (Durlík et al., 2016; Libben & Titone, 2009; Macizo et al., 2010; Pivneva et al., 2014; von Studnitz & Green, 2002), or null effects, with no differences to controls (de Groot et al., 2000; Dijkstra, van Jaarsveld, & ten Brinke, 1998; Elston-Güttler & Gunter, 2009; Elston-Güttler, Gunter, & Kotz, 2005; Lemhöfer & Dijkstra, 2004; Schwartz & Kroll, 2006; Zhu & Mok, 2020).

Further evidence that apparent *on-line* cross-language effects may actually reflect processing beyond lexical access comes from Hoversten and Traxler (2016), who examined the influence of sentence context on interlingual homograph processing in an eye-tracking study with Spanish–English bilinguals and English monolinguals.

Participants read English sentences containing interlingual homographs, such as *pie* (meaning ‘foot’ in Spanish), in conditions where either the target language meaning (L2 English) or the non-target language meaning (L1 Spanish) was congruent with the sentence context. For example, in one condition, the L2 meaning was congruent while the L1 meaning was incongruent (e.g., *While eating dessert, the diner crushed his pie accidentally with his elbow.*). In the other condition, the L1 meaning was congruent while the L2 meaning was incongruent (e.g., *While carrying bricks, the mason crushed his pie accidentally with the load.*).

The study found no differences in early reading times (e.g., first-pass and regression-path times) between bilinguals and monolinguals when the target language meaning of the interlingual homograph was incongruent with the sentence context. Congruency effects emerged only in later processing measures (e.g., total reading time), where bilinguals resolved the slow-down from incongruent conditions more quickly than monolinguals. This suggests that bilinguals initially accessed the L2 meaning of the homograph regardless of semantic bias but later reanalysed the word to access and integrate the L1 meaning when required.

These findings may also provide a reinterpretation of results reported by Jouravlev and Jared (2014), who tested Russian–English bilinguals reading English sentences biased toward the Russian meaning of English–Russian homographs (e.g., *To see Tom’s throat, the doctor asked Tom to open his ... widely.*). The target words (indicated by ...) were either the English translation corresponding to the homograph’s Russian meaning (e.g., *mouth*), the homograph itself (e.g., *pot*), or an unrelated control word (e.g., *net*). The ERP responses revealed no significant differences in the N400 amplitude between interlingual homographs and their semantically appropriate English translations. Furthermore, the N400 for homographs was significantly smaller than for control words. In contrast, English monolinguals showed an increased N400 amplitude for both interlingual homographs and control words.

Jouravlev and Jared (2014) interpreted these findings to suggest that, unlike monolinguals, bilinguals were able to use the Russian meaning of the homograph to successfully integrate the word into the English sentence context. They argue that this supports the activation of the Russian reading of the homograph, and further its conceptual representation, as posited by the BIA+ model. However, the study only analysed mean amplitudes within the 350–450 ms epoch after stimulus onset. Visual inspection of the ERP waveforms indicates that the divergence between bilinguals and monolinguals, as well as between homographs and control words, emerged around 300 ms after stimulus

onset. The exact interpretation of the N400 component is still up for debate, with findings suggesting that it reflects word-level processing during lexical access (e.g., Lau et al., 2008; Lee & Federmeier, 2008; Van Petten & Kutas, 1990), and others suggesting that it involves sentence-level post-lexical processes, such as the integration of word meaning into context (e.g., Hagoort et al., 2004, 2009). More recently, the component has been suggested to reflect a dynamic, integrated process of both bottom-up word-level processing and top-down sentence-level processing (e.g., Kutas and Federmeier, 2011, see also Kuperberg and Jaeger, 2016; Michaelov et al., 2024; Nour Eddine et al., 2022, 2024). Despite the ongoing discussion about its function, it remains possible that Jouravlev and Jared's N400 effects may not have occurred during lexical access but rather during subsequent semantic integration.

One could therefore argue, in line with Hoversten and Traxler (2016), that the findings of Jouravlev and Jared (2014) are incompatible with models such as the BIA+ model (Dijkstra & van Heuven, 2002), which assume initial non-selective access. Hoversten and Traxler (2016) propose that instead, their results support the “zooming-in” hypothesis (Elston-Güttler, Gunter, & Kotz, 2005), which proposes that global language context as well as sentence context can modulate language selectivity during lexical access. This hypothesis comes from an ERP study where German–English bilinguals performed lexical decisions on target words (e.g., *poison*) following sentences with low semantic constraint ending in a prime word that was either an interlingual homograph (e.g., *gift*, ‘poison’ in German) or controls (e.g., *shell*). Half of the participants watched a German film before the experiment, while the other half watched the English version of the same film. Significant inhibitory homograph priming effects were observed in the ERP responses (N400 and N200) as well as the reaction times in the group who saw the German film, while no effects were observed for participants who viewed the English version of the film. Their findings are interpreted within the BIA+ model, where the non-target language meaning of the interlingual homograph is made inaccessible due to combined effects of the language and sentence contexts on the task/decision system.

Indeed, interlingual homograph effects, like cognate effects, are modulated by sentence context and proficiency. For example, in an L2 RSVP task where interlingual homographs were embedded in sentences with high vs. low semantic constraint, Schwartz and Kroll (2006) found no differences in mean naming latencies and accuracies for interlingual homographs in proficient Spanish–English bilinguals (Experiment 1) and a difference in error rates for less proficient bilinguals (Experiment 2), suggesting that for semantically driven tasks like sentence comprehension, ‘lexical competitors

that are exclusively form-related do not become strongly activated' for more proficient bilinguals (p. 208). However, in an eye-tracking study with French–English bilinguals, Libben and Titone (2009) found that early processing measures, such as gaze duration, were slower for interlingual homographs compared to control words, with no interaction between word type and sentence constraint (high vs. low). In contrast, there were no differences between interlingual homographs and controls in high constraint sentences for later comprehension measures (e.g., total reading time). According to the authors, this suggests that bilingual lexical access is non-selective early in processing, but that 'semantic feature restrictions' leading to lexical expectations in high-constraint sentences may restrict non-selective activation to become more selective at the later stages of comprehension. It is therefore clear that both L2 proficiency and semantic constraint, as well as the task, can modulate interlingual homograph effects.

The study of Libben and Titone (2009) also found a modulating effect of L2 proficiency, but only for cognate facilitation. More specifically, readers who were more proficient in their L2 elicited less cognate facilitation overall. In a later eye-tracking study using the same materials and a less proficient group of French–English bilinguals, Pivneva et al. (2014) explored whether differences in executive control (as measured by antisaccade, nonlinguistic Simon and Stroop, and number Stroop tasks) has an effect on cross-linguistic activation. They found that greater executive control attenuated interlingual homograph inhibition, but it did not have an effect on cognate facilitation. Instead, L2 proficiency was found to modulate the cognate effect such that less proficient readers displayed greater cognate facilitation. This led the authors to suggest that the driving mechanism behind the two effects is different: whereas the effect observed for interlingual homographs seems to be driven by cross-linguistic activation, the cognate effect seems to occur because 'language-unique' control words have a 'lower functional frequency' (p. 793) than cognates, because of the lack of overlap in form.

These studies on interlingual homograph effects suggest that they are not robust, as the effects do not always occur, even in single-word processing. Although some of the evidence suggests that they reflect cross-language activation, as we saw from the results of e.g., Pivneva et al. (2014), it is unclear which mechanisms would constrain this activation. Furthermore, the evidence from Hoversten and Traxler (2016) suggests that the effects could reflect integration processes occurring post-lexical access.

The data presented here suggest that, in the early stages of L2 learning, both meanings of an interlingual homograph are activated. However, as L2 proficiency increases, it seems possible to constrain activation to the target language meaning,

particularly in contexts with clear semantic constraints or in strict one-language settings. Based on the current evidence, it remains unclear whether the non-target language meaning and (if distinct) lexical representation are activated at all in these instances. Indeed, the data from Hoversten and Traxler (2016) and the many studies reporting null effects (e.g., Elston-Güttler, Gunter, & Kotz, 2005) for interlingual homographs suggest that it is possible that only the relevant target language representations are activated.

From a learning perspective, increased L2 proficiency and exposure might strengthen within-language connections, enabling the network of L2 representations to become more independent. This is a plausible way in which selective or partially selective access could occur later in L2 learning. Alternatively, it is possible that representations for interlingual homographs are less enhanced compared to controls because they are more difficult to learn. This idea aligns with Costa et al. (2017) account, discussed earlier, and also the proposal above on how translation ambiguous words may be difficult to learn. Evidence from the monolingual domain indicates that interference or competition from an ambiguous word's alternative meaning can impede their learning (see Rodd, 2018, for a review). It is therefore possible that learners erroneously assume interlingual homographs to be cognates, leading to the establishment of links to incorrect L1 meanings. Although empirical evidence does not seem to support this assumption, as interlingual homographs seem to be acquired similarly to non-cognate control words (Elias & Degani, 2022; Marecka et al., 2021), further investigation is necessary. For instance, Elias and Degani (2022) hypothesise that a learning advantage from the form overlap of interlingual homographs could cancel out interference on learning from their competing meanings, resulting in null effects.

### **1.3.4 Intra-Sentential Code-Switching**

Further insights into whether sentence context can constrain word recognition to become selective comes from studies exploring the processes of code-switched words within sentences. Additional support for the hypothesis that the interlingual homograph effect in Jouravlev and Jared (2014) reflects integration processes comes from Hoversten and Traxler (2020), who conducted an eye-tracking study examining language selectivity and top-down language control during reading in Spanish–English bilinguals. In Experiment 1, participants read sentences (e.g., *We saw that his ... had a horrible scar.*) where the target word (indicated by ...) was non-switched (e.g., *hand*), code-switched (e.g., *mano*), or a pseudoword (e.g., *erva*). The experiment consisted of two blocks, one

where L1 Spanish sentences were read, and another where L2 English sentences were read. Overall, the eye-tracking measures suggested that beginning from early stages of processing, code-switched words were less accessible than non-switched words but more accessible than pseudowords. This was affected by trial order, with the reading times and skipping rates of code-switched words becoming less like the pseudowords with increased exposure to code-switches. The authors take this as evidence for initial, fully selective access that turns into partially selective access over the course of the experiment. There was also a difference between L1 and L2 reading, with L1 Spanish code-switches in L2 English reading eliciting a fully selective pattern with no differences to pseudowords, while the accessibility of L2 English code-switches in L1 Spanish reading was in between non-switches and pseudowords.

In a second experiment, Hoversten and Traxler (2020) used a boundary change paradigm to implicitly present the code-switched words and the pseudowords to participants to investigate the partial selectivity hypothesis further in a one-language context. Here, these words were presented in the parafoveal preview position, and replaced by their non-switched equivalents upon fixation. The experiment consisted of two blocks for each language, Spanish and English. Parafoveally presented code-switched words were skipped equally often, suggesting that lexical representations in the non-target language were not accessible during the earliest stages of word recognition. The authors interpret these results as support for the selective access hypothesis, indicating that participants zoomed in and out of a language depending on exposure to it and the non-target language.

Hoversten and Traxler (2020) list some interesting reasons why their results are not compatible with the substantial body of evidence supporting non-selective access and activation in single-language contexts. First, they did not use language-ambiguous words, like cognates or interlingual homographs, which, citing Wu and Thierry (2010), they argue could trigger activation of the non-target language. Second, no explicit evidence of the non-target language was presented to participants in their second experiment. They also reference the developmental account of Costa et al. (2017) (discussed above) and conclude that their data are more compatible with this account than on-line parallel activation models, such as the BIA+ model (Dijkstra & van Heuven, 2002).

Hoversten and Traxler (2020) take their results as evidence that top-down information can restrict access to the non-target language early in processing. This interpretation challenges non-selective accounts, like the BIA+ model, which does not allow for top-

down effects of language membership information. They suggest that a plausible mechanism by which global language context could influence lexical activation is inhibitory feedback from the language nodes in the BIA model. Furthermore, they argue that ‘the BIA model would need to be updated to allow language nodes to accumulate activation over time to dynamically change global activation levels of each language according to the language mode.’ (p. 9). This adaptation would allow for a ‘proactive language control’ mechanism, wherein the ‘current global language context’ can contribute to ‘flexible and dynamic changes in the relative activation level of each language’ (p. 14).

In a study examining semantic preview effects in bilingual reading, Hoversten and Martin (2023) used the boundary change paradigm to investigate how bilinguals extract semantic information from parafoveal words within and across languages. Semantic preview effects, which result in shorter reading times when the target is fixated, occur when a preview word is semantically related to the target. Hoversten and Martin cite evidence showing that in bilingual reading, cross-language semantic preview benefits appear to be limited to cases where form similarity exists between the preview and the target, such as with cognates or interlingual homographs (e.g., Altarriba et al., 2001).

In their experiment, intermediate to high proficiency Spanish–English bilinguals read sentences in Spanish or English (e.g., *They were asking the student questions about his toad because they were interested.*). The preview word was either identical to the target (e.g., *toad*), a within-language synonym (e.g., *frog*), a within-language semantically unrelated word (e.g., *hill*), a cross-language translation equivalent (e.g., *sapo* – meaning ‘toad’), or a cross-language semantically unrelated word (e.g., *loma* – meaning ‘hill’). Within-language semantic preview benefits were similar in size when reading in L1 Spanish and L2 English. In contrast, there was no evidence of semantic preview benefits between-languages, even for translation equivalents.

Hoversten and Martin (2023) concluded that bilinguals can extract semantic information from within-language parafoveal previews, regardless of target language dominance, but that this does not extend to between-language previews. Their findings replicate prior studies demonstrating no cross-language semantic preview benefits and extend previous findings of sublexical preview benefits. They propose that while form information can be processed independently of language membership, semantic information from the non-target language is blocked due to deactivation of the non-target language. This interpretation challenges the BIA+ model, which assumes fully non-selective activation and would predict cross-language semantic preview benefits.

Instead, their findings align with the partial selectivity hypothesis (Hoversten & Traxler, 2020; Hoversten et al., 2015), which allows for complete deactivation of the non-target language in single-language reading contexts.

### **1.3.5 Language Membership and Sublexical Cues**

As we have seen, it seems that cues, such as global and local language context, which signals the language membership of current and upcoming input can constrain word recognition to become selective. However, according to Dijkstra and van Heuven (2002) and the BIA+ model, language membership information is not available early enough to affect word identification. Although this assumption is based on empirical evidence (e.g., Dijkstra, van Jaarsveld, & ten Brinke, 1998), more recent evidence suggests that this assumption should be reconsidered. For example, in a simultaneous semantic and language membership classification task with Spanish–English bilinguals, Hoversten et al. (2015) found faster reaction times and earlier ERP onset latencies of the go/no-go effect in language categorisation (target vs. non-target language) than in semantic categorisation (animate vs. inanimate), indicating that language membership information becomes available earlier than word meaning during recognition. The effect was also larger in language categorisation, which the authors suggest implies that identification of language is stronger than that of semantic categories. The ERP responses further revealed larger word frequency effects for go than no-go trials in the language categorisation task, but no differences in semantic categorisation, suggesting that the depth of processing in the target and non-target languages can be modified based on language membership information.

The authors propose that these findings open the possibility for selective access at the semantic level, where language membership information acts as a filter to constrain activation of a language based on task relevance. They argue that these results challenge the BIA+ model, particularly its separation between the word recognition system and the task/decision system, and suggest that the model's language nodes should play a more active role. Instead, the findings align with the original BIA model, which accommodates top-down inhibition by language nodes on non-target language words and allows task demands to influence lexico-semantic processing.

In a separate study investigating the time course of access to orthographic cues for language membership, Hoversten et al. (2017) used an oddball paradigm. Spanish–English bilinguals judged whether English and Spanish target words and pseudowords,

categorized as either target-language-like or non-target-language-like based on bigram frequency, belonged to the target language. ERP responses revealed an early effect of orthographic cues (target-like vs. non-target-like) between 200–275 ms, followed by a later effect of lexicality (word vs. pseudoword) from 300–500 ms. Target-like stimuli elicited larger N2 and P3 component responses, reflecting sensitivity to orthographic typicality. Furthermore, target-like pseudowords had higher false alarm rates than non-target-like pseudowords.

These findings suggest that orthographic cues, as previously discussed in this Section as well as Section 1.2.1, can activate language membership information even in the absence of lexical information. Hoversten et al. (2017) extend prior work (e.g., Casaponsa & Duñabeitia, 2016; Casaponsa et al., 2014, 2015; Lemhöfer & Radach, 2009) by showing that language-specific orthographic cues contribute to early identification of language membership and selective access. They challenge the assumption in the BIA+ model that language membership information is only available later and primarily affects the task/decision system (see also Casaponsa et al., 2020; van Kesteren et al., 2012). Instead, their results suggest that orthographic cues activate language membership early, which can reduce or modulate non-selective activation, allowing for partially selective access. These findings remain consistent with the original BIA model, which supports early inhibition of non-target language representations by language nodes.

## 1.4 Neural Language Models

Before moving on to the outline of this thesis, I briefly review research that uses recurrent neural language models trained on the task of next-word prediction to simulate bilingual sentence processing, as this is the method used in Chapter 3. This line of research is well-established in the monolingual domain and has predominantly been used to study on-line language processing with a focus on syntactic phenomena, such as garden-path effects (e.g., van Schijndel & Linzen, 2018a, 2018b) and agreement attraction (e.g., Arehalli & Linzen, 2020). It began with the work of Elman (1990), who showed that Simple Recurrent Networks (SRNs) can learn sequential dependencies in language. The next important milestone in language modeling was the development of Long Short-Term Memory (LSTM) models (Hochreiter & Schmidhuber, 1997), which have gated memory mechanisms that allow the model to remember previous input. More recently, great advancements have been made with model architectures such as

Transformers (Vaswani et al., 2017), of which ChatGPT (OpenAI, 2023) is the most well-known application.

Neural language models have been shown to exhibit psychometric predictive power (Wilcox et al., 2020), with their surprisal values (i.e., negative log probability of a word given its preceding context) demonstrated to correlate with behavioural measures, such as reading times (e.g., Goodkind & Bicknell, 2018; Merkx & Frank, 2021; Wilcox et al., 2020), as well as physiological measures, such as electroencephalography (EEG) (e.g., Frank et al., 2015; Merkx & Frank, 2021) and functional Magnetic Resonance Imaging data (fMRI) (e.g., Schrimpf et al., 2021; Willems et al., 2016). Although work has shown that larger models employing attention-based mechanisms, such as Transformers, more accurately predict human behavioural data (in the monolingual domain; Merkx and Frank, 2021; Wilcox et al., 2020, though see Roslund and Matussevych, 2022 for evidence favouring SRNs in the bilingual domain), the focus here is on Recurrent Neural Networks (RNNs), which process input sequentially and have been argued to be more cognitively plausible (Merkx & Frank, 2021).

In rough terms, language models compute conditional probabilities of words given their context, which allow them to predict the most appropriate or likely continuation of a sentence or sequence based on patterns and relationships learned from the training data. The input is a sequence of words (or smaller units, like letters or character bigrams), converted into word embeddings, which are numeric representations of words that allow for their representation in vector space. These types of representations capture relationships between words, and the model dynamically adjusts them based on the context in which the words appear. For instance, the embeddings for words like *cat* and *dog* are likely to end up more closely represented in vector space than *cat* and *potato* because they are semantically more similar, and thus occur more often in similar syntactic contexts, i.e., their co-occurrence statistics are more similar.

The model outputs a probability distribution over possible next words, based on the context and the learned representations. In layman's terms, at the start of training, an RNN makes random guesses about the next word based on its memory of the previous tokens (i.e., context window). Different models have context windows of different sizes, or in other words, they differ in how many prior tokens are used to generate the predictions. During training, the model compares its guesses to the actual next word from the training data, generating an error signal, where the difference between the prediction and the actual word is quantified. This difference is then used to update the model weights through the backpropagation algorithm, allowing the model to learn

from its mistakes and to make better predictions over the course of training.

Models such as the LSTM model (Hochreiter & Schmidhuber, 1997), which I use in Chapter 3, can be trained on large amounts of (unannotated) data, consisting of for instance large text corpora. This allows for more naturalistic training data compared to the earlier SRNs (though see Linzen, 2020). Another benefit of computational language models is that one can manipulate language exposure, i.e., what data the model is exposed to. The importance of this will become evident in Chapter 3.

Compared to SRNs, LSTMs have better mechanisms for handling long-term dependencies. This is achieved through three gates — the forget gate, the input gate, and the output gate — which together determine how the memory of the network is updated. The forget gate determines how much of the previous context (i.e., from the previous time step or hidden state) is retained, allowing the network to “forget” information that is no longer relevant. The input gate evaluates the extent to which new information should update the network’s memory, based on the current input and previous hidden state. Lastly, the output gate determines what information from the updated memory should be passed on to the next hidden state. Together, these mechanisms allow the model to retain and discard information over time, which allows the network to base its predictions on both local and global context.

In research on bilingual sentence processing, RNNs were first used by French (1998) to explore how a bilingual lexical network may emerge through unsupervised learning. French’s SRN (1998) is a distributed connectionist model of bilingual memory, aimed at explaining how the organisation of the bilingual lexicon develops. It does this by simulating bilingual language acquisition: an SRN model (Elman, 1990) is trained on two micro-languages (12 items consisting of subject nouns, verbs, and object nouns) simultaneously, with the items combined into simple SVO sentences with no language tags, which were presented to the model in a mixed order. Over time, the model’s internal representations clustered by language, while their activation patterns were largely overlapping. French’s work demonstrated that such a structure can emerge on the basis of statistical regularities of two-language input.

SRNs have also been used within the domain of bilingual sentence comprehension to investigate whether constraints from working memory or statistical learning may better explain effects such as the grammaticality illusion in bilinguals (Frank et al., 2016). In another study, Frank (2014) trained SRNs on either Dutch, English, or the two languages combined, and found that self-paced reading times of Dutch–English bilinguals in L2 English were better predicted by surprisal values from the bilingual

language model, whereas L1 Dutch reading times correlated more with the surprisal values of the monolingual Dutch model.

It thus seems as models that work well as monolingual language models can be applied to bilingual data without the need to tweak model architecture. According to Frank (2021) and as discussed in Section 1.2.1, this reduces the risk of a model lacking explanatory adequacy, i.e., its ability to explain a phenomenon. This makes them a valuable tool for simulating and testing hypotheses about bilingual sentence comprehension, an approach that is further explored in Chapter 3.

## 1.5 Outline of This Thesis

The evidence presented so far suggests that, contrary to the assumptions of traditional word recognition models, the word recognition system can be constrained to operate in at least a partially language-selective manner. The main focus of this thesis is to understand (1) the mechanisms of lexical access during non-native language comprehension, in particular with regard to non-selective activation, and (2) how the structure of the bilingual mental lexicon emerges in sequential language learning. Using both computational and behavioural methods, I investigate what happens when a word in a non-native language is processed, considering the activation of lexical representations both on-line and during learning of the non-native language. I further explore how learning a new language impacts the organisation of the mental lexicon and how these changes influence non-native language processing. The primary research questions are as follows:

1. Are lexical representations consistently activated non-selectively across languages during non-native language word recognition?
2. How are the representations of native and non-native language words influenced by different learning mechanisms, and how does this affect their activation and processing?
3. Do bilinguals predict in their L1 when using their L2?
4. How do context and language proficiency affect bilingual word recognition?

In Chapter 2, I review literature relevant to these questions as a theoretical contribution, focusing on whether the cognate effect can be explained as a within-language

phenomenon. Cognates may have distinct representations in the bilingual mental lexicon compared to monolingual lexicons due to differences in learning processes (Costa et al., 2017, 2019). I consider whether on-line cross-talk — co-activation of both languages during learning — leads cognates to develop representations akin to higher-frequency words in a single language. Evidence from cognate processing in both comprehension and production is evaluated to determine whether a learning-based account better explains these phenomena compared to traditional accounts emphasising on-line non-selective activation.

In Chapter 3, I explore the cognate facilitation effect from an exposure-based perspective by training a neural language model on two languages as input. The RNN models discussed in Section 1.4 are particularly suitable to test hypotheses related to statistical learning. One such hypothesis within bilingual language comprehension is the cumulative frequency hypothesis of cognate facilitation. According to this hypothesis, cognate processing is facilitated because they occur in a bilingual's two languages, making their word frequencies cumulative across the languages, in contrast to non-cognates, which are only encountered in one language. Therefore, cognates behave like higher-frequency words do for monolinguals (and within a language), and non-cognates like lower-frequency words, in that the former are recognised faster than the latter.

In this chapter, I investigate whether the cognate facilitation effect can be explained by cumulative word frequency and bilingual language exposure patterns. Using an LSTM model (Hochreiter & Schmidhuber, 1997) implemented by van Schijndel and Linzen (2018b), I manipulate the proportions and order of language input during training to simulate different levels of bilingual language proficiency and exposure. The model's predictions are compared against bilingual eye-tracking data from two cognate reading experiments. Our results show that models trained on larger proportions of L1 input relative to L2 display lower surprisal values for cognates compared to non-cognates. This difference in surprisal values for the two word types is explained by their cumulative word frequencies counted from the training data, providing support for the cumulative frequency hypothesis. Furthermore, the size of the cognate effect correlates with the model's L2 perplexity, suggesting that the linguistic knowledge (i.e., language proficiency) contributes to the cognate facilitation effect in language models.

In Chapter 4, I examine the influence of the language of instruction (i.e., the language used to learn a new language) on cognate processing and its implications for the organisation of the mental lexicon. I hypothesise that the language of instruction affects how cognates are represented and processed, with form overlap being more pronounced

between languages actively used during learning than between the new language and an unused but known language. To test this, I conduct a lexical decision experiment with trilinguals proficient in Dutch, French, and English, grouped based on whether they learned English through Dutch or French instruction. Lexical decision times for Dutch–English and French–English cognates and non-cognates were analysed. Our findings reveal a significant three-way interaction between the language of instruction, cognate language, and cognate status, suggesting that cognate facilitation only occurs between the new language and its language of instruction.

In Chapter 5, I investigate whether cognates are more predictable than non-cognates during L2 sentence processing using a visual world paradigm. Dutch–English bilinguals view four objects while listening to English sentences that predicted a specific target (e.g., *The man wanted to buy a new ...*). Two objects matched the sentence continuation (e.g., a pipe and a wallet, one of which had a name that is cognate in Dutch and English), while two distractor objects were incompatible (e.g., a priest and a plumber). Eye movements were tracked to determine whether cognates elicited more predictive looks than non-cognates. Although target objects receive significantly more predictive looks than distractors after the verb onset, no differences emerged between cognate and non-cognate target objects. These results suggest that bilinguals may exhibit selective predictive processing, with limited cross-language activation during L2 comprehension.

Lastly, in Chapter 6, I bring together these empirical findings and discuss their implications for our understanding of non-selective activation in bilingual lexical access and predictive processing.



## **Chapter 2**

# **Can Learning Explain Cognate Effects in Bilingual Comprehension and Production?**

Most theories of bilingual word recognition and production assume parallel, on-line activation of both languages, even in one-language contexts. A considerable amount of the evidence for parallel activation comes from the study of translation equivalents with similar form and meaning across two languages (cognates), which bilinguals process differently to translation equivalents with no form similarity across languages (non-cognates). The on-line account has been queried by Costa et al. (2017), who suggest that the cognate effect can be explained by learning: on-line cross-talk during second language acquisition would lead to different representations for cognates compared to non-cognates in the bilingual mental lexicon. In this chapter, we focus on these two hypothesised origins of the cognate effect and consider the extent to which cognate effects can be explained by learning and on-line activation.

## Foreword

In this chapter, I introduce the cognate facilitation effect and provide a comprehensive review of this effect in bilingual language comprehension and production. Building on the discussion of cross-linguistic effects in Chapter 1, which focuses on learning-based versus on-line (i.e., assuming non-selective activation) explanations of these effects, this chapter continues to explore these accounts, with a specific focus on cognate effects.

The chapter lays the theoretical framework for the learning-based explanations of cognate effects examined in this thesis in three ways. Firstly, it evaluates the extent to which learning-based and on-line explanations can account for cognate effects, with conclusions that are empirically tested in Chapter 4. Second, it addresses the hypothesis that cognate effects may reflect a frequency effect in disguise, which is further explored through computational modeling in Chapter 3. Lastly, it examines how cognate effects have been interpreted as evidence for non-selective activation during on-line processing, which is relevant for Chapter 5, where non-selective activation is investigated in the context of non-native language prediction. This chapter has been published as Winther, Matuszevych, and Pickering (2023) in *Bilingualism through the Prism of Psycholinguistics* (pp. 104–129) by John Benjamins Publishers.

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## 2.1 How Do a Bilingual's Languages Affect Each Other?

Bilinguals often find themselves in situations where only one of their languages is understood. In these one-language contexts, to what extent does their other (non-target) language affect processing in the (target) language in use? A considerable amount of relevant research on this question in bilingual language processing has focused on lexical access — that is, how word representations in the bilingual mental lexicon are accessed. The general orthodoxy is that lexical representations across languages are activated in parallel, meaning that activation is not constrained to only one language when a word's meaning is accessed. This view, termed the language non-selective hypothesis (Beauvillain & Grainger, 1987), is captured in theoretical models of bilingual language

production (Costa et al., 1999; Dijkstra et al., 2019) and comprehension (Dijkstra & van Heuven, 1998, 2002; Dijkstra et al., 2019). A contrasting view is the language selective hypothesis (Gerard & Scarborough, 1989), in which activation of lexical candidates is restricted to the target language.

One way that has been used to test how a bilingual's languages affect each other is to look at the processing of words that have similar form and meaning in the two languages, namely cognates. Cognates are translation equivalents that also overlap considerably in written and/or spoken form across two languages (e.g., *hospital*, which has the same spelling and meaning in Spanish and English). The overlap in form may be partial, as with non-identical cognates (e.g., the Spanish word *gato* is cognate with English *cat*), or complete, as with identical cognates (e.g., *hospital* above). If bilinguals process cognates differently to control words (matched on frequency, length, etc.) that do not share form with their translation equivalents (such as Spanish *mesa* – 'table'), it suggests that the two languages of a bilingual speaker influence each other in some way. But the exact nature of such influences, and how they contribute to the patterns observed in cognate processing, can be difficult to identify.

Below, we consider two hypotheses about the source of activation of cognates relative to non-cognates. The first, which is widely accepted and assumes language non-selectivity, involves the on-line co-activation of representations from both languages in the bilingual mental lexicon. In other words, when a cognate word is processed, parts of its representations in both languages become active. The second hypothesis about the source of cognate activation is due to the manner in which they are learned and subsequently represented in the mental lexicon. This hypothesis assumes that cognates are represented differently from translation equivalents that do not overlap in form and is compatible with both selectivity and non-selectivity. In other words, cognate words are represented differently because their shared form and meaning cause them to be learned differently. If so, then cognates are likely to be processed differently to cross-linguistically unrelated words. The present chapter discusses cognate processing in a second language (L2) in light of these two hypotheses, on-line activation and learning, to better understand the role each of them plays in accounting for cognate effects.

We first review theoretical assumptions and models of bilingual lexical processing and how they explain consistent findings of a cognate facilitation effect (e.g., Costa et al., 2000) (Section 2.2). These findings have shown that bilinguals process cognates faster than non-cognates, and this processing difference is not observed in monolinguals. This

facilitated processing is standardly explained by on-line activation. We then discuss an account explaining cognate effects in terms of how cognates are learned and represented. Next, we consider the predictions of a learning account for cognate processing in various one-language tasks (i.e., in this context, tasks where only the L2 is used) in comprehension and production (Section 2.3). The predictions are discussed along with empirical findings of cognate effects to assess the extent to which these findings can be explained by learning. Based on the evidence we review, we argue that cognate effects are consistent with a learning account, but also with an on-line activation account and that the findings from cognate processing are not sufficient to distinguish between the accounts.

## **2.2 Explanations of the Cognate Facilitation Effect**

Studies of L2 lexical production and comprehension consistently find that processing is facilitated for cognates relative to words that are unrelated to their translation in form. This effect holds for different behavioural tasks, such as picture naming (e.g., Costa et al., 2000), lexical decision (e.g., Dijkstra et al., 1999), priming (e.g., de Groot & Nas, 1991), and reading (e.g., Duyck et al., 2007; Libben & Titone, 2009). The effect has also been found in studies using neurophysiological methods, such as ERP (Midgley et al., 2011; Strijkers et al., 2010). The degree of cross-linguistic form overlap correlates with the size of the effect. For instance, greater orthographic overlap leads to larger facilitation effects in general, whereas greater phonological overlap leads to larger facilitation only for (orthographically) identical cognates (Dijkstra et al., 2010). The facilitation effect is also modulated by language proficiency: for instance, Schwartz and Kroll (2006) found that bilinguals with a higher L2 proficiency elicited smaller cognate facilitation. Below, we first review how cognate effects have been interpreted in terms of on-line co-activation of two languages in models of bilingual lexical processing. We then discuss how the effects can be explained by learning, based on an account of cross-linguistic effects by Costa et al. (2017) and use this to consider the extent to which empirical data supports this account. Lastly, we discuss the implications of our theoretical analysis for further research on cognate processing.

### 2.2.1 On-Line Parallel Activation

Many researchers assume that cognate effects are an indicator of the on-line, simultaneous activation of lexical representations across languages. The rationale is that the activation of cognate words originates from two sources rather than one, unlike non-cognates, thereby aiding the process of lexical retrieval. As an example, consider the Spanish–Catalan cognate *gato* (Catalan: *gat* – ‘cat’) used by Costa et al. (2000) to explain the activation process in production: if the cognate is produced in Spanish, both the Spanish and Catalan lexical representations are activated simultaneously, starting at the conceptual level. When this activation spreads to the phonological level, the phonemes /g/, /a/, and /t/ receive activation from two sources (i.e., the lexical representations in the two languages), which eases phonemic selection. In the case of non-cognate production, for example *mesa* – ‘table’ in Spanish (Catalan: *taula*), the lack of overlap between phonological segments leads to smaller activation of the phonemes and by consequence, no facilitation.

In reading comprehension, cognate facilitation has been interpreted as an orthographic semantic priming effect (Dijkstra et al., 2010, p. 286). Here, the idea is that the overlapping representations of a cognate’s orthography and semantics are co-activated. For instance, in Dutch–English bilinguals, seeing a cognate such as *tomato* in English activates both its English and Dutch orthographic representations *tomato* and *tomaat*, respectively. This activation flows from the two sources at the orthographic level to the semantic level and feeds back to the orthographic level, resulting in a higher level of activation of a cognate compared to non-cognates. This account is supported by Dijkstra et al.’s experimental results: they found a strong increase in cognate facilitation (measured by lexical decision times) going from orthographically near-identical to identical cognates.

This idea may be better conveyed in terms of a quantitative model where these assumptions are implemented. MULTILINK is a recent, localist-connectionist computational cognitive model of bilingual (written) word recognition and production proposed by Dijkstra et al. (2019). It integrates the assumptions of two models: the Bilingual Interactive Activation model (BIA/BIA+: Dijkstra & van Heuven, 1998, 2002; van Heuven et al., 1998), a computational model of bilingual word recognition, and the Revised Hierarchical Model (RHM: Kroll & Stewart, 1994), a theoretical model of lexical and conceptual representation in bilingual memory. Because MULTILINK goes beyond these earlier models with regards to simulations of cognate processing, we

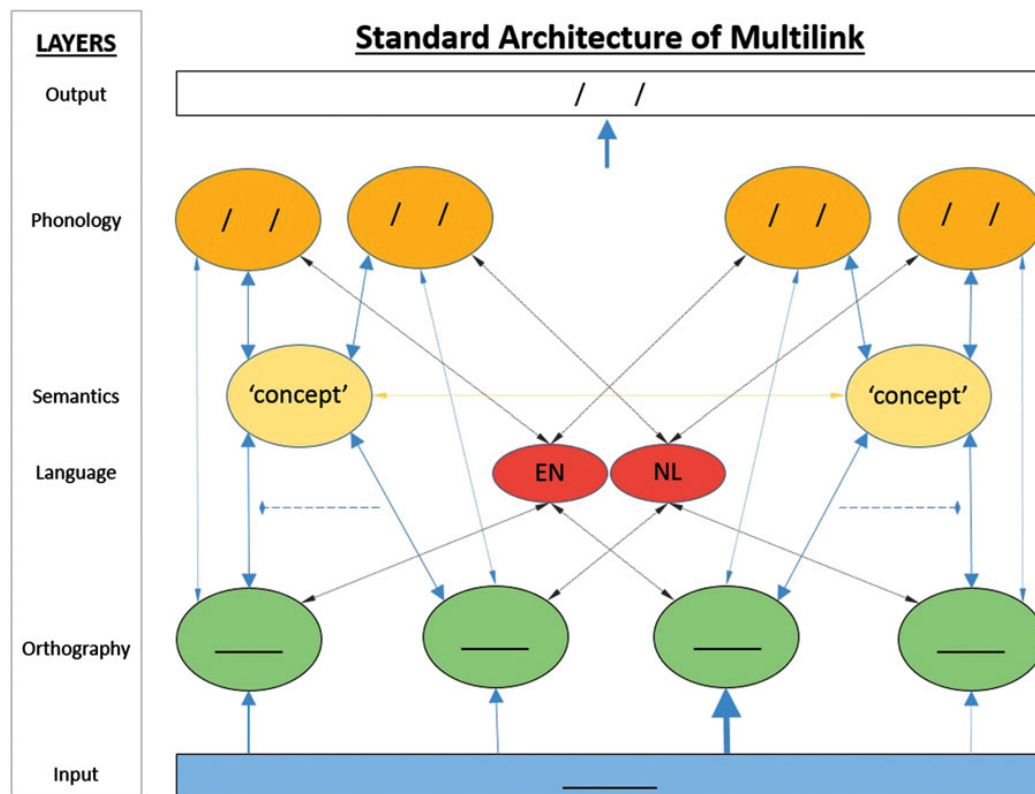
sketch out its assumptions below.

MULTILINK assumes language non-selective activation of words stored in an integrated lexicon, meaning that the representations of word candidates relating to an input word are co-activated and compete across languages. Its standard architecture is shown in Figure 2.1. An input word (indicated by the blue underscore at the bottom of Figure 2.1) activates orthographic representations (green underscores in Figure 2.1) in the model's lexicon to an extent that depends on their usage frequencies and orthographic overlap (measured by normalised Levenshtein distance) between the input and stored word representations. Phonological representations are activated directly (via orthography) and indirectly (via semantics). In the case of Dutch–English bilingual processing, if a cognate such as *tomato* is presented as input to the model, co-activation of the orthographic representations *tomato* and *tomaat* occurs. They both activate their shared semantic representation, and then the semantic and orthographic representations together activate the phonological representations they are linked to. Compared to a non-cognate input word, the co-activation leads to a quicker increase in activation of the concept, which in turn results in earlier and stronger feedback to the orthographic (recognition) or phonological (production) output representations. According to MULTILINK, resonance between the representations at the orthographic and semantic levels is the driving force of cognate facilitation. The results of Dijkstra and colleagues' simulations correlate with findings from experimental studies that use Dutch–English L2 lexical decision tasks (Dijkstra et al., 2010; Vanlangendonck et al., 2020) and word naming (Dijkstra et al., 2019). Thus, MULTILINK predicts that cognates would elicit shorter reaction times (RTs) than non-cognates.

### 2.2.2 Cognate Effects in Light of Learning

The on-line accounts of Costa and his colleagues (1999, 1999, 2000) and Dijkstra et al. (2010, 2019) have provided a fairly orthodox explanation of cognate effects in production and comprehension. Other proposals have relied less on simultaneous, on-line activation and have considered the nature of cognate representations as the driving mechanism of the effects instead. Below, we sketch out one account of how the representations of cognates in the mental lexicon may lead to their facilitated processing based on a proposal from Costa et al. (2017).

The idea that the way cognates are learned may contribute to their facilitated processing has been suggested by several authors, such as Costa et al. (2006, p. 143),



**Figure 2.1.** Architecture of the symbolic lexical network of the MULTILINK model. All activation flows bidirectionally as it is an interactive model. The output is dependent on task. Reprinted from Dijkstra et al. (2019).

de Groot (2010, p. 247), and Dijkstra et al. (2012, p. 69). Costa et al. (2017) proposed a model of how the process of learning a second language may explain findings attributed to on-line parallel activation of lexical entries across two languages. Their hypothesis accounts for how the L2 lexical structure emerges in relation to various observations of cross-linguistic effects. For instance, in an ERP experiment by Thierry and Wu (2007), Chinese–English bilingual participants performed semantic relatedness judgments on semantically related and unrelated word pairs (e.g., *train* and *ham*) whose translations were either form-related in Chinese (*huo che* and *huo tui*, respectively) or not form-related. A reduced N400 amplitude was found for the form-related word pairs compared to those words with no relationship in Chinese. This reduction in the N400 amplitude applied irrespective of semantic relatedness. An English monolingual control group did not show this effect, whereas a monolingual Chinese control group showed a reduced amplitude (in addition to behavioural priming effects as measured by accuracy and RTs, which was not observed in the bilingual group) for form-related pairs of Chinese words.

Thierry and Wu (2007) interpreted their findings as a result of on-line activation

of translation equivalents during processing. In contrast, the explanation of Costa et al. (2017) is that, during learning, the native language structure is carried over to the emerging structure of the L2 because of on-line co-activation of the languages. Thierry and Wu's results could thus be explained by the proposal that when learning the English word *train*, a Chinese learner activates its L1 translation *huo che* through semantics, which activates its form-related neighbour *huo tui* ('ham'). This in turn activates the L2 representation *ham*. Because *train* activates *ham* in this manner, a connection is developed between them. The resulting L2 structure thus has 'traces' of the L1. With increasing proficiency and automaticity, parallel activation is gradually restricted. When sufficient proficiency is reached, the co-activation of native language representations may cease, but the connection between *train* and *ham* remains in the L2 English mental lexicon.

Oppenheim et al. (2018) criticised some aspects of the learning account in a response to Costa et al. (2017). They queried whether the link between form-related (and semantically unrelated) L1 words is likely to survive when new (semantic) associations between words that co-occur in the L2 are encountered. For instance, they asked what happens when Chinese–English bilinguals learn valid and useful within-L2 associations, such as associating *ham* with *cheese*. They argued that the differences in the strength of the connections between co-activated words should be reflected in the magnitude of the observed effect of (L1) form overlap. Of course, Costa et al. do not agree with this proposal — in their account, strong connections are caused by both the within-language relationships and by the relationship that has been established as a consequence of between-language transfer. Note also that the model of Costa et al. provides just one possible learning-based account of Thierry and Wu's results. For example, it is also possible that co-activation persists in proficient bilinguals, but that it occurs only in two-language contexts. Alternatively, co-activation might always occur, but it is too limited or too slow to explain Thierry and Wu's findings.

The learning account of Costa et al. (2017) assumes two mechanisms for word learning in a second language: phonological (or orthographic) forms are linked to semantic concepts via spreading activation (i.e., activation spreads between related representations) and Hebbian learning (i.e., representations that are activated together develop a connection). These mechanisms contribute to the inheritance of the L1 organisation of lexical items in the emerging L2 lexicon. When accounting for cognate facilitation as a learning effect, it is of course necessary to assume that activation flows between languages during learning, just as it continues to do in the on-line

activation account. In other words, co-activation of words and their translations occurs during learning. But once a sufficiently high level of proficiency is attained, non-target language representations cease to be activated. Consequently, this leads to different representations for cognates than non-cognates in bilingual lexical memory. The representations of cognate words are “enhanced” such that they are more accessible than non-cognates, which is why their processing is (typically) easier and faster. If this hypothesis is correct, it means that a cognate word is represented similarly to a higher-frequency word. That is, it has a stronger representation and therefore requires less evidence to reach a threshold for identification (Morton, 1979). To put it differently, in order to successfully recognise or produce a cognate word, its representations require less activation compared to non-cognates. Crucially, on-line activation between L1 and L2 occurs during learning, but may be shut off after a sufficient proficiency is attained — either completely, with no co-activation at all, or partly, such that co-activation is restricted, for instance, to very early (sub-lexical) stages of word recognition (a ‘language-independent encoding process prior to language-specific lexical access’ (Gerard & Scarborough, 1989, p. 312)).

Studies investigating the acquisition of cognate words are consistent with this account, as cognate words have been found to be easier to learn and less prone to be forgotten (de Groot & Keijzer, 2000; de Vos et al., 2019; Lotto & de Groot, 1998; Tonzar et al., 2009). For example, de Groot and Keijzer (2000) asked experienced L2 learners to learn made-up translations of L1 words in a new pseudo-language. Testing participants one week after training, they found that these pseudo-cognates (with 40–75% overlap with the paired L1 word) are easier to learn and less susceptible to being forgotten than non-cognates (with no overlap). Similar results have been found up to six months after training with German–Dutch cognates (de Vos et al., 2019). These findings suggest that the strengths of representation may differ for cognates vs. non-cognates, at least early in L2 acquisition. Their findings suggest that processing differences between cognates and non-cognates may be due to learning. Of course, the ease of learning cognates might reflect on-line activation during the initial stages of acquisition, which is compatible with the on-line activation account.

As an interim summary, the main differences between the two accounts are the following. An on-line account explains cognate effects in terms of activation as a cognate is processed. In contrast, a learning account explains them in terms of the representation of cognate words in the mental lexicon. In the latter case, cognate facilitation occurs because less activation is required from the input for successful

recognition of a cognate, compared to non-cognates. Of course, a hybrid account is also possible, with cognate effects being due to a combination of on-line activation and learning.

## **2.3 A Theoretical Review of Cognate Effects in Bilingual Processing**

We now review evidence of cognate effects, explaining the results in terms of the two accounts discussed above. We argue that both accounts are able to interpret the empirical findings, and the research carried out so far on cognate processing does not allow us to distinguish between the two accounts. The effects seen in cognate processing are influenced by many factors, such as the presence of a sentence context and the predictability of a cognate, the cognate's word class, the degree of form overlap between cognates, and the L2 proficiency of the bilingual. We consider each of these and review studies on bilingual comprehension and production separately below. Our focus is on tasks that do not require overt translation, or where the stimuli are not mixed between L1 and L2, as such tasks would induce a dual-language mode, in which different patterns of word activation may be observed overall (Wu & Thierry, 2010).

### **2.3.1 Cognate Processing in Isolation**

In the learning account, a cognate word would in general behave the way a higher-frequency word does in monolingual speakers, because of its enhanced representation caused by learning (Costa et al., 2019). As such, for cognate words processed in isolation (without a sentence context), the predictions are that both recognition and production times are facilitated compared to matched non-cognate control words. This difference between cognate and non-cognate processing should not be observed in monolinguals. If the hypothesis is correct, we expect that cognates (vs. non-cognates) should show the same patterns as have been observed for higher-frequency (vs. lower-frequency) words, for example relating to the time-course of processing. The cognate effect should appear early in processing, for instance, on first fixation and first pass durations in eye-tracking, and as early as 140 ms after stimulus onset in an ERP study (Sereno et al., 1998). On this account, it is not due to on-line effects but due to the distinctive properties of cognate words enabling them to develop stronger representations compared to non-cognates in memory during learning. Note that the on-line account also predicts that cognate

processing is facilitated relative to non-cognates. However, in this case the facilitation is caused by on-line activation rather than higher resting level of activation, and in this case, it is unclear whether the effect would be similar to a frequency effect.

### 2.3.1.1 Comprehension

*Visual word recognition.* It is consistently found that bilinguals make faster lexical decisions for cognates than non-cognates: using highly fluent Dutch–English bilinguals, Dijkstra, van Jaarsveld, and ten Brinke (1998) found significantly faster RTs for (orthographically) identical cognates compared to control words (a 25 ms effect). Similar results have been obtained with identical French–English cognates (Peeters et al., 2013) and with phonologically similar different-script Japanese–English cognates (Miwa et al., 2014). Dijkstra and colleagues interpret their findings as evidence of on-line activation of the cognate form in the non-target language, which combines with activation of the cognate form in the target language to increase the activation of the cognate’s semantic representation. They attribute the cognate effect to the higher activation of the cognates’ partially shared semantic representation. In other words, both the activated target and non-target orthographic representations of the cognate contribute to the activation of its meaning. The authors further hypothesise that this convergent activation at the semantic level sends strong feedback to the orthographic level. They argue that to properly evaluate hypotheses about language selectivity and non-selectivity in lexical access, levels of representation require a distinction between form (orthography) and content (semantics). According to the authors, lexical access is non-selective at both these levels. The distinction between form and content is useful in demonstrating the differences between on-line accounts and the learning account. The latter is compatible with the assumption that lexical access is language-selective throughout or is non-selective at the early stages of processing, possibly only at the form level. The facilitation observed in the lexical decision experiments discussed above could be due to the higher activation of cognates than non-cognates and would thus be compatible with the learning account as well as with the on-line account.

Interestingly, further studies have found that the magnitude of cognate effects is larger for identical cognates than non-identical cognates (Dijkstra et al., 1999; Duyck et al., 2007). In L2 English lexical decision, Dijkstra et al. (2010, Experiment 1) found that RTs decreased with increased orthographic similarity between a cognate and its translation. The effect was largest for identical cognates, which also benefited from phonological similarity with their translation equivalents. The authors’ explanation is

that identical cognates elicit the largest co-activation and that the two representations of non-identical cognates inhibit each other, as seen by the reduction in facilitation when form overlap decreases. From a learning perspective, the smaller facilitation for non-identical cognates could be explained by the idea that the amount of cross-talk between languages during L2 word acquisition may vary depending on the degree of form overlap. Non-identical cognates may thus show a smaller effect because their cross-linguistic relationship is less salient than the relationship of identical cognates, leading them to be learnt less well.

Cognate effects have also been found when the relationship across two languages is not so salient. For example, cognates across Arabic and Hebrew are written differently because of their markedly different orthographies, although they still overlap in phonology. Degani et al. (2018) used such words to explore whether non-selective language co-activation occurs across orthographies. In a one-language semantic priming study, Arabic–Hebrew bilinguals judged whether two visually presented words in their L2 Hebrew were related in meaning. When primed with a word related in meaning to the target word, participants were more accurate and marginally faster at responding if the prime was an Arabic–Hebrew cognate than if it was a non-cognate. This study demonstrates that cognate effects persist even when strong language membership cues are present in the absence of overlap between orthographies (i.e., bottom-up effects from orthography are absent). The authors suggest that the degree of overlap between L1 and L2 representations (at any level of representation) may vary depending on the language pair and be dynamic over time for individual bilinguals. For instance, they suggest that increased L2 proficiency may result in L2 phonological representations that are more distinct from the L1 phonological representations (i.e., the pronunciation of L2 words becomes more native-like), and hence a decrease in sub-phonological similarity. This is a plausible way in which increased L2 proficiency could reduce cross-talk between languages, as suggested by the learning account (e.g., Costa et al., 2019).

An ERP study by Peeters et al. (2013) offers insight into how a cognate's frequencies of occurrence in the target and non-target languages affect its processing. In their study, late French–English bilinguals performed a lexical decision task in their L2 English. The critical target words were either orthographically identical cognates with high or low L1 and L2 frequencies (e.g., *assassin* which has a high frequency in French, but low frequency in English as its near-synonym *murderer* is more common), or L2-specific control words with high or low frequency. The RT data showed a significantly larger facilitation effect for cognates with low L2 frequency compared to those with high

L2 frequency. Furthermore, cognates with high L1 frequency elicited faster RTs than cognates with low L1 frequency. The ERP data revealed a significant N400 effect of cognate status, with controls yielding a more negative-going wave (indicating more difficulties in processing) than cognates. A separate analysis on the cognate words revealed that the N400 effect of L2 frequency was longer (300–700 ms) and more widely distributed, whereas the (anterior) N400 effect of L1 frequency was shorter (400–500 ms). Additionally, cognates with low L2 frequency and high L1 frequency elicited a more negative N400 compared to cognates with high L2 frequency and low L1 frequency. The authors suggest that cognates with low L2 frequency benefit more from their L1 translation equivalents than high L2 frequency cognates. Based on these findings, and the assumption that both the L1 and L2 representations of a cognate are co-activated, Peeters et al. proposed that even though both the target and non-target language word frequencies of a cognate affects its processing, its frequency in the target language has a larger influence on processing than its frequency in the non-target language.

In an ERP study with similar design, Xiong et al. (2020) investigated the processing of visually identical Japanese–Chinese cognates, which can sound different across the two languages. Their Chinese–Japanese participants performed an L2 Japanese lexical decision task on two-character cognates and control words. Interestingly, in lexical decision times, the cognate effect was larger for cognates with low Japanese word frequency (52 ms, relative to a low-frequency non-cognate) than high Japanese frequency (28 ms, relative to a high-frequency non-cognate). Their ERP measures revealed a more negative early frontal waveform for controls than cognates, about 250 ms after word onset (FN250). Compared to cognates, control words elicited a larger negative amplitude in the central-parietal region about 400 ms after word onset (N400). However, in contrast to Peeters et al., the effects of L1 word frequency on cognate processing was only marginally significant in both the behavioural and ERP measures. The authors interpret cognate facilitation as a result of on-line co-activation. They suggest that the early FN250 effect may reflect co-activation of L1 and L2 orthographic representations at a pre-lexical level, as the FN250 is thought to reflect processing at the form-level (Holcomb & Grainger, 2006). This activation of the orthographic level then moves toward the semantic level, activating the meaning of the cognate word as reflected in the later N400 effect, leading to a facilitated recognition of cognates compared to controls. However, Xiong et al. conclude that further work is required to investigate the possibility of an interaction of pre-lexical phonological and semantic

information contained in Chinese/Japanese characters.

If cognate effects instead are ascribed to learning, a possible explanation for the RT and ERP results of Peeters et al. (2013) of easier processing of cognates with high L2 frequency is that they are encountered more often during L2 learning, thus strengthening their L2 representations, which leads to easier processing. In contrast, a cognate with low L2 and high L1 frequency may be more difficult to process because it is mainly encountered during L1 learning. Its L2 representation is therefore not as prominent as for the words encountered often in the L2. The benefit of a high L1 frequency on processing could potentially be due to more cross-talk during learning (and, thus, enhanced representations) for cognates with high L1 frequency. The evidence from Xiong et al. (2020) of co-activation at an early, pre-lexical level is also compatible with a learning account that assumes non-selective activation early in lexical access. Furthermore, the larger amplitude of N400 for controls found in Peeters et al. and Xiong et al. could reflect a frequency effect, as the N400 has been found to be smaller for isolated words with high frequency compared to low-frequency words (Barber et al., 2004). This is consistent with the assumption of a learning account that cognates are processed more easily than non-cognates because cognates behave like high-frequency words due to their enhanced representation. We return to a discussion of the effect of word frequency in bilingual language processing below, but first we review whether cross-linguistic effects in visual word recognition differ from those observed in spoken word recognition.

*Spoken word recognition.* One potentially problematic study for a learning account of cognate effects is that of Blumenfeld and Marian (2007). They employed a visual world eye-tracking paradigm to record the eye-movements of German–English and English–German bilinguals, as well as English monolinguals, in spoken English word recognition. Participants were presented with four objects, which included (1) either an English–German cognate or a non-cognate as the target, and (2) either a similar sounding German competitor or a control item, plus two filler objects. Participants were asked in English to identify the object and click on it. When the target word was a non-cognate (e.g., *desk* – ‘Pult’ in German), there was no difference between the percentages of looks at competitor (e.g., *Deckel* – ‘lid’ in English) and control items in English–German bilinguals and also in the English monolinguals. In contrast, competitor items received significantly more looks than control items for German–English bilinguals than for both other groups. For cognate targets (e.g., *pianist* – ‘Pianist’ in German), English–German bilinguals behaved like German–English bilinguals, with the percentage of looks being

significantly larger for competitor (e.g., *Pik* – ‘spades’ in English) than control items.

Blumenfeld and Marian’s conclusion is that both languages are co-activated when proficiency (in the language of the competitor items) is high (in the case of German–English bilinguals) for both cognate and non-cognate targets, whereas co-activation of a less proficient language (in English–German bilinguals) does not always occur but can be “boosted” by cognate targets. However, it could be that a visual world paradigm activates dual-language mode: upon seeing an object, participants may activate the name of the object in their native language. If this is the case, then objects with cognate names, which have been argued to induce dual-language mode (Wu & Thierry, 2010), may activate the other language more than objects with non-cognate names. Therefore, it could be that the cognate stimuli activate the non-target language, which could explain the competition from form-related items in the non-target language.

### 2.3.1.2 Production

Cognate facilitation has also been found in language production, where bilingual speakers name pictures faster if their names in the two languages are cognates than if they are non-cognates (e.g., Costa et al., 2000; Hoshino & Kroll, 2008). In Costa et al. (2000), highly proficient Catalan–Spanish bilinguals and Spanish monolinguals named pictures in Spanish whose names were either non-identical cognates (e.g., *gato* – *gat*, ‘cat’) or non-cognates (*mesa* – *taula*, ‘table’). One aim of the study was to test whether the phonology of non-selected lexical items would be activated. The authors found that Catalan–Spanish bilinguals produced cognate names faster than non-cognate names, whereas Spanish monolinguals named both types of pictures with similar latencies. Additionally, they found in a second experiment that the magnitude of the cognate effect depended on language dominance: non-dominant (Catalan) speakers elicited a larger effect compared to dominant (Spanish) bilinguals. They argued that cognates are facilitated because the phonological nodes receive activation from two sources (the selected target language nodes and the non-selected non-target language nodes), leading to a quicker selection of phonemes. With non-cognates, activation of the non-selected lexical node activates the non-target phonology, but since this is different from the target language phonology, there is no facilitation. According to Costa et al., the effect of language dominance on naming could be due to activation of phonological nodes from lexical nodes being greater in the dominant than the non-dominant language. This may be because activation is larger for the dominant compared to non-dominant language words (i.e., asymmetric activation), or because the connections between lexical and

phonological nodes are stronger in the dominant than non-dominant language (difference in connection strength).

An alternative explanation for the origin of the cognate effects in naming, which does not assume on-line co-activation, was proposed by Costa et al. (2006). This idea involves differences in learning difficulty between cognates and non-cognates. Costa et al. argued, in line with the learning account, that cognates are learned more easily and more robustly than non-cognates. Additionally, if two alternatives are available, a cognate would be used more often during learning: ‘a Spanish–English unbalanced bilingual may be more inclined to use the word “construct” (“construir” in Spanish) than the word “build” (“construer” in Spanish)’ (Costa et al., 2006, p. 143). They argue that this learning advantage may lead to the advantage for the processing of cognates compared to non-cognates later in life.

Strijkers et al. (2010) investigated the time-course of ERP correlates of the frequency effect and the cognate effect in overt picture naming (L1 and L2) in highly proficient bilinguals (Spanish–Catalan and Catalan–Spanish). They found that the ERPs of high vs. low target-language frequency words and cognate vs. non-cognate words were ‘remarkably comparable’: the ERPs of high-frequency items diverged from the ERPs of low-frequency items around 180 ms after picture presentation, with greater ERP amplitudes for low- compared to high-frequency items. A similar pattern was found in the cognate conditions, with non-cognates eliciting greater amplitudes than cognates, from around 190 ms after the target presentation in L1 and L2 naming. The authors suggest that cognate status and word frequency have a similar impact on naming latencies and that the cognate effect may be a frequency effect in disguise: the cross-linguistic form overlap of cognate translations leads to a strong activation of their lexical representations in both the target and the non-target language every time a cognate is encountered. This co-activation may only occur for cognates, or alternatively, is very weak for non-cognate translations. Because cognates are co-activated more often, this leads to a higher-frequency representation for cognates compared to non-cognates.

Although we agree with the conclusion that the cognate effect may be a frequency effect in disguise, we argue that the assumption of activation of non-target language lexical representations (i.e., beyond the sub-lexical activation of the shared phonological segments) every time a cognate is heard or uttered is not necessary. The similarities between word frequency effects and cognate effects observed here could be because both cognates and high-frequency words have easily accessible representations in memory (Costa & Pickering, 2019). The ease of lexical access could thus be ascribed to learning

(although it is challenging to determine if and when this cross-talk ceases to occur: see e.g., Costa et al., 2019, for a discussion), because cognates require a lower threshold of activation to be selected for production.

Another line of research on cognate processing deals with tip-of-the-tongue (TOT) states. These states occur when a failure of word retrieval associated with access to some features about a word (Brown & McNeill, 1966). Bilinguals experience TOT states more often than monolinguals (Gollan & Acenas, 2004). This effect has been found, for instance, in Hebrew–English bilinguals (Gollan & Silverberg, 2001) and in Spanish–English and Tagalog–English bilinguals (highly proficient or dominant in English) when tested in L2 English using a picture naming task (Gollan & Acenas, 2004). Interestingly, bilinguals performed similarly to monolinguals when presented with pictures whose names are cognates (Gollan & Acenas, 2004). In their discussion, Gollan and Acenas considered a possible explanation for cognate effects, which assumes a similar logic as the learning account discussed here: that cognates are ‘better learned’ than non-cognates due to the prominence of the cross-linguistic similarity, such that the similarity operates as a ‘powerful retrieval cue’ (p. 264).

Although Gollan and Acenas (2004) do consider this proposal, they at the same time suggest three problems with it. We believe these problems do not, in fact, challenge the learning account. First, they argue that the assumption that co-activation of lexical representations occurs during learning and then fails to occur (after learning) is similar to the cognate account of Costa et al. (2000), but without the ad-hoc assumption that co-activation ceases. However, we argue that it is not clear why the assumption of reduced or restricted co-activation with increased proficiency and automaticity should be problematic. Their second point is that because cognates are very common in many language pairs, their similarity is notable when they are first learned, but over time it is likely that this ‘novelty’ becomes less salient. Here, it is not clear why the similarities between cognates should become less salient over time. Thirdly, they point out that a clear mechanism for their observed effects is not provided by this account: for instance, it is unclear at which processing level the effect of cognate words’ ease-of-learning would arise in accounts of TOTs. We argue that a learning account could offer a plausible resolution of these issues: since TOT states are thought to occur due to incomplete activation of lexical candidates (A. S. Meyer & Bock, 1992), cognates may be less likely to stay in this state because, according to the learning account, they require less activation for successful selection.

Cognates have also been found to affect articulation. Amengual (2012) tested

different groups of Spanish–English bilinguals (both L1 Spanish and L1 English) in the naming of Spanish targets (e.g., *teléfono* – ‘telephone’ (cognate) or *teclado* – ‘keyboard’ (non-cognate)) in Spanish sentences (*Yo puedo decir ...* – ‘I can say ...’). For all groups, although cognates were named faster than non-cognates, their voice onset times (VOT) were longer (more English-like, i.e., less native-like) compared to non-cognates. This difference was not found in a non-English speaking (Spanish–Catalan bilinguals) control group. In a similar study, Jacobs et al. (2016) tested different groups of English–Spanish bilinguals (classroom and immersion (intermediate proficiency) vs. advanced learners (high proficiency)). In the naming of cognate (e.g., *cable*) vs. non-cognate (e.g., *cabe*) targets (in isolation) in L2 Spanish, a difference between cognate and non-cognate VOT was only found in the classroom learners. Jacobs et al. ascribe the differences between the groups to the ability to inhibit the non-target language, rather than proficiency, as the advanced learners had significantly higher L2-proficiency than both the classroom and immersion learners, but the immersion learners were “forced” to inhibit their L1 due to the immersion programme. From the perspective of an on-line account, it could be that on-line connections between representations are different depending on how learning occurred, which is why the effect is observed only in the classroom learners. However, the findings also agree with the assumption of a learning account that learning interacts with lexical representations: it could be that immersion learners are less affected by the activation of L1 representations during learning, which results in the ability to maintain native-like contrasts in the L2.

In summary, we have looked at different production and comprehension tasks and language pairs in which cognate facilitation has been observed. This facilitation is modulated by the degree of form overlap but is also present when the form overlap is missing in either phonology or orthography. Most of the findings are consistent with a learning account, although also with the full on-line activation account. Some may argue that when experimental word stimuli are processed one by one, the presence of identical or non-identical cognates could unintentionally encourage activation of the non-target language during their processing (Comesaña et al., 2015; Wu & Thierry, 2010). It is therefore important to consider how cognate effects manifest during sentence processing, as we do below.

## 2.3.2 Cognate Processing in Sentence Contexts

When a word is processed in a sentence context, its predictability in the given sentence context influences its processing. The predictability of a target word (e.g., *book*) in a given sentence can be manipulated by biasing the preceding context (measured by cloze probability) toward that word. The resulting sentences are referred to as semantically constraining (or high-constraint) sentences (e.g., *He went to the library to get a ...*), where the probability of the target word *book* is high. These stand in contrast to low-constraint sentences (e.g., *He went to the shop to buy a ...*) which are not biased toward one specific target word, so the context provides little information about the probability of the next word being *book*. Below, we discuss how processing of cognates in comprehension and production is affected by their predictability in a sentence context.

### 2.3.2.1 Comprehension

In monolingual reading times, the effects of predictability and frequency seem to be additive (Staub, 2015). That is, the effect of a word's frequency is not affected by its predictability in a given sentence, meaning that the effect of predictability is the same for high- and low-frequency words. Staub further concluded that this activation has an early effect on processing, either during the pre-lexical processing of features or at the earliest stages of lexical processing (i.e., letters or features).

Extending the effects of frequency and predictability to bilingual comprehension, and assuming that the mechanisms of predictive processing are similar for bilinguals (although bilinguals may predict more slowly or to a lesser extent in their L2 compared to native speakers (Ito et al., 2017, 2018; C. D. Martin et al., 2013)), what are the implications for cognate processing and predictability? According to the learning account, cognates receive additional activation during learning, just as high-frequency words do, so that both cognates and high-frequency words have a high resting level. Therefore, the effect of cognatehood may be the same as the effect of frequency — that is, the interaction between predictability and cognatehood may be additive. A learning account predicts that cognate effects on eye movements should therefore not be modulated by contextual constraint. An on-line account, exemplified by the predictions of the BIA+ model, assumes that linguistic context, such as semantic constraint, can directly affect activity in the word identification system through increased semantic activation feeding back to the orthographic level (Dijkstra & van Heuven, 2002; Van Assche et al., 2011). Thus, according to the BIA+ model, top-down information from

semantic constraint may constrain the degree of non-selective access. However, because of the lack of a specific mechanism of how sentence context may influence lexical access (Schwartz & Kroll, 2006), the predictions for an on-line account are underspecified.

Libben and Titone (2009) examined how cognate processing is affected by semantic constraint in an eye-tracking study. Their highly proficient French–English bilinguals read L2 English sentences which were either highly or weakly semantically constraining toward identical cognates or their controls. The early eye-tracking measures, such as first fixation duration, gaze duration, and skipping rate, showed more rapid processing for cognates than controls in both low- and high-constraint sentences. For the later measures, such as go-past time and total reading time, cognate processing was facilitated only in low-constraint sentences. The study further found that bilinguals with higher L2 proficiency displayed smaller cognate facilitation effects than less proficient bilinguals. The authors suggest that semantic and orthographic pre-activation increase the lexical expectations of upcoming input (at the orthographic level). Because these lexical expectations are language-specific, lexical access is initially non-selective and becomes more selective at the later stages of comprehension. In another similar study with Dutch–English bilinguals, cognate facilitation in high-constraint sentences was found for both early and late measures (Van Assche et al., 2011, Experiment 2). Based on this result, Van Assche et al. argue that top-down semantic restrictions have a ‘very limited influence’ on lexical activations and that both the early and late stage of word recognition is non-selective.

Pivneva et al. (2014) ascribe the different findings of Libben and Titone (2009) and Van Assche et al. (2011) to the participants’ L2 proficiency. They used the same stimuli and paradigm as Libben and Titone but tested less proficient French–English bilinguals, whose L2 proficiency was more similar to that of the bilinguals in Van Assche et al. Replicating Van Assche et al., cognate facilitation was found for both early (gaze duration) and late (total reading time) eye-tracking measures in high-constraint sentences, suggesting that cognate facilitation in high-constraint sentences is limited to early stages of processing only if the L2 proficiency is sufficiently high as in Libben and Titone’s participants. Pivneva and colleagues suggest two reasons why proficiency should modulate effects of sentence constraint on cognate facilitation. The first is that less proficient bilinguals are less likely to use contextual information efficiently (e.g., C. D. Martin et al., 2013). The second is that divided L1 and L2 exposure may result in non-cognates being encountered less frequently overall by bilinguals (compared to cognates), such that cognate effects are driven by control words and not by cognates

(Gollan et al., 2011; Titone et al., 2011). These explanations are consistent with a learning account, if one assumes that with increased exposure to the L2 the differences between the resting level activations of cognate and non-cognate words become smaller. However, they are also consistent with an on-line account where the smaller cognate effect associated with higher proficiency (i.e., changed relative proficiency between the L1 and L2) may be due to a reduced relative contribution of activation of non-target language forms (Bultena et al., 2014).

In order to better understand the effect of sentence context on language non-selectivity, Lauro and Schwartz (2017) compared the effect sizes from studies on cognate facilitation in high- and low-constraint sentence contexts in a meta-analysis. The analysis of studies on L2 processing revealed that overall, cognates are processed faster than non-cognates in both a high- and a low-constraint context, but that the effect is larger in low-constraint contexts. It was further found that task type modulates the magnitude of the effect. Cognate effects are stronger in tasks that require overt responses from participants, such as lexical decision, compared to experiments measuring more implicit behaviour, such as eye movements in reading. Lauro and Schwartz suggest that a sentence context alone does not contribute sufficient linguistic information to constrain lexical access to only one language, but that a semantically constraining sentence context can attenuate cross-linguistic lexical activation. They conclude that the extent to which the non-target language influences processing in the target language is dynamic, meaning that the activation of the non-target language changes during the time-course of lexical access (from recognising the word to integrating it with the semantic context) and during the comprehension of a sentence. This activation depends on comprehension demands and the availability of information allowing for a decision to make a response or to move on in a sentence.

### **2.3.2.2 Production**

Lauro and Schwartz's (2017) meta-analysis included some language production studies, which we will now look at in more detail. In language production, an interaction between frequency and predictability has been found in L2 processing. For instance, Gollan et al. (2011) compared predictability and word frequency effects between comprehension and production. Spanish–English and Dutch–English bilinguals with different levels of L2 English proficiency named pictures (Experiment 1) or read words (Experiment 2, eye-tracking) embedded in high- or low-constraint sentences. The word frequency of the picture name was manipulated (high/low). An interaction between frequency and

sentence constraint was found in naming, but not for any of the standard measurements (gaze duration, first fixation duration and total fixation times) in reading, confirming earlier findings from the monolingual domain in naming (Griffin & Bock, 1998) and reading (Staub, 2015). More specifically, semantic constraint reduced the size of the frequency effect in production, but not in comprehension. Thus, if one assumes a pure learning account, where cognate words are represented similarly to high-frequency words, a reduced cognate effect should also be observed when cognates are named in a highly constraining sentence context. As in comprehension, an on-line account also predicts that semantic constraint can modulate cognate effects through pre-activation of semantics in production. Yet, as we discuss above, due to the lack of a more specific mechanism of how this occurs in the BIA+, it is not clear whether the effects may be fully or only partially eliminated.

Schwartz and Kroll (2006) used an RSVP naming task to investigate cognate processing in sentences where the predictability of identical, or near-identical (e.g., *band – banda*) cognates was manipulated. In this task, Spanish–English bilinguals saw L2 English sentences which were rapidly presented one word at a time, and they had to name a target word out loud. A cognate facilitation effect, measured by naming latencies, was found only in low-constraint sentences (for both more proficient and less proficient bilinguals), but not in high-constraint sentences. Crucially, there was an interaction between constraint and cognate status, and cognate facilitation was eliminated in high-constraint sentences. In contrast, Starreveld et al. (2014) in their picture naming experiment with Dutch–English bilinguals found that production of (identical or non-identical) cognates in L2 sentences was facilitated in both high- and low-constraint contexts. They interpret these findings as evidence that co-activation occurs even when producing words in context. They explain cognate facilitation in terms of Costa et al.’s (2000) model of cognate effects in language production, which we discussed in Section 2.2: the phonological segment receives activation from two sources rather than one, due to co-activation. The constraining semantic context pre-activates features of the upcoming word, and may even fully activate its semantic representation, such that the name of the picture is available before it occurs.

The findings from both studies discussed in the above paragraph (Schwartz & Kroll, 2006; Starreveld et al., 2014) can also be explained by a learning account. In production, frequency effects are modulated by sentence constraint (Gollan et al., 2011; Griffin & Bock, 1998). This could explain why Schwartz and Kroll (2006) observed no effect in the high-constraint condition. If a cognate word behaves like a higher-frequency

word due to its representation, it could be that a strongly constraining sentence context modulates the facilitation caused by bottom-up effects, leading to smaller facilitation. Then why was a cognate effect observed in the high-constraint condition in Starreveld et al. (2014)? First, their data is not clear on whether sentence constraint significantly interacted with cognate status in L2 processing as the analysis was performed on pooled data from naming in L2 and L1. Second, reiterating a point we made in Section 2.3.1 about the visual world paradigm and dual-language mode, it could be that the naming of pictures (as opposed to written words as in Schwartz and Kroll's study) induces dual-language mode. Therefore, it could be that seeing and naming a cognate object activated its name also in the participants' L1. However, it is clear that further research is required to fully understand how cognate status interacts with sentence constraint in both production and comprehension, as the studies discussed here do not fully converge on their findings.

## 2.4 Discussion

In this chapter, we discussed how cognate facilitation effects can be accounted for by two different accounts, on-line co-activation of target and non-target languages vs. cognate learning. The first account assumes that the representations of cognate words are likely to be activated faster and to a higher degree than non-cognates during lexical access. This occurs because activation from the target and non-target representation of cognates converges at the semantic level, and results in feedback activation to the lexical representations. The second account assumes that cognate representations require less activation than non-cognates in order to be recognised or produced successfully. Here, the target and non-target readings of a cognate do not contribute to its facilitation during processing on-line, but rather they contribute during learning, such that cognates' representations become enhanced compared to non-cognates. This hypothesis is one way in which cognate effects can be accounted for in terms of their manner of learning and representation. It is similar to earlier but less exhaustive accounts which emphasize cognate learning and representation in memory when explaining cognate effects (Costa et al., 2006; de Groot, 2010; Dijkstra et al., 2012). The learning account finds support in studies showing that cognates are learned faster and retained for longer in memory, compared to non-cognates (de Groot & Keijzer, 2000; de Vos et al., 2019; Lotto & de Groot, 1998). We further reviewed other evidence of cognate processing to assess the extent to which this supports (or at least is consistent with) a learning account.

Results from studies of cognate processing in isolation (i.e., when cognates are processed without a sentence context) are consistent with both accounts, as both predict facilitation of cognates compared to control words. Perhaps the strongest form of evidence for a learning account is the finding of Strijkers et al. (2010) that cognates diverge from non-cognates at about the same time as highly frequent words diverge from words with low frequency in their ERP amplitudes. This suggests that the two effects may have the same origin, but whether on-line co-activation continues across the lifespan of a bilingual, or whether it is sufficient that co-activation is restricted to a learning phase (and to dual-language contexts) where the processing context often involves both languages, is yet an open question. It is also possible to combine the learning account with the assumption that co-activation of target and non-target languages continues to occur throughout the life of a bilingual. For instance, it may well be that initially, during comprehension, form-related neighbours across languages are briefly activated (Gerard & Scarborough, 1989). Whether the activation of the non-target language takes place continuously throughout the process of lexical access, and whether this always leads to the activation of the meaning of non-target translation equivalents, is unclear. However, future research could explore further how cognate status interacts with variables that are known to interact with word frequency, such as regularity (Sereno & Rayner, 2000), to examine whether the similarities between cognate and frequency effects are only superficial, or whether they reflect that similar mechanisms are driving the effects.

When cognates are processed in a sentence context, we saw less conclusive evidence of cognate facilitation if the context is semantically constraining. The existing findings also emphasised the role of L2 proficiency in cognate processing. A learning account provides a straightforward account of why cognate effects may be modulated by proficiency. Costa et al. (2019) hypothesised that increased proficiency and automaticity in the L2 may change the organisation of the bilingual mental lexicon (for instance through “unlearning”, i.e., reducing the footprint of L1 on the L2), which may also lead to greater autonomy between a bilingual’s languages. One of the strengths of a learning account is thus its focus on how learning interacts with lexical representations (Costa & Pickering, 2019) across different stages of bilingualism, which allows for flexibility when it comes to different aspects of bilingualism, such as language use. One way to investigate how learning interacts with lexical representations is to examine cognate effects in trilinguals. For example, if a Dutch–Spanish–English trilingual learns English in Dutch school, do they show stronger cognate effects between Dutch and English than Spanish and English?

Based on the evidence reviewed in this chapter, we argue, in line with Costa et al. (2006), that cognate effects are consistent with explanations and models that do not assume on-line co-activation. Although here we have focused on evidence from cognate processing in one-language contexts, and the evidence from cognate processing in isolation consistently shows cognate effects, investigations into how cognate facilitation is affected by, for instance, word frequency and sentence constraint are not conclusive, as the findings are compatible with both learning and on-line accounts. We further argue that cognate effects by themselves cannot prove that parallel activation always occurs during on-line processing. This is because, as suggested by Pivneva et al. (2014), it could be that the cognate effect is driven by the lower functional frequency of words unique to the L2. Further explorations of the role of L2 proficiency and L1 and L2 word frequencies are required to better understand cognate effects and their underlying mechanisms.

As mentioned by Costa et al. (2006), the processing of other types of words that are ambiguous with regard to which language they belong to, for instance false friends, may offer additional insight into language interaction. These words share form but not meaning across languages and could therefore help to tease apart the effects of cross-linguistic semantic and form processing. A comparison between the processing of cognates and false friends from the perspective of a learning account would therefore be necessary to draw better conclusions about how learning and co-activation affects processing on different levels of representation.



## Chapter 3

# Cumulative Frequency Can Explain Cognate Facilitation in Language Models

Cognates — words which share form and meaning across two languages — have been extensively studied to understand the bilingual mental lexicon. One consistent finding is that bilingual speakers process cognates faster than non-cognates, an effect known as cognate facilitation. Yet, there is no agreement on the underlying factors driving this effect. In this paper, we use computational modeling to test whether the effect can be explained by the cumulative frequency hypothesis. We train a computational language model on two language pairs (Dutch–English, Norwegian–English) under different conditions of input presentation and test it on sentence stimuli from two existing studies with bilingual speakers of those languages. We find that our model can exhibit a cognate effect, lending support to the cumulative frequency hypothesis. Further analyses reveal that the size of the effect in the model depends on its linguistic accuracy. We interpret our results within the literature on cognate processing.

## Foreword

Building on the idea of cognate facilitation as a frequency effect introduced in Chapter 2, this chapter uses computational models to simulate and test hypotheses about bilingual sentence processing. Specifically, it uses recurrent neural networks (introduced in Chapter 1) to test the cumulative frequency hypothesis — the idea that the processing of (identical) cognates is facilitated because bilinguals encounter them more frequently than non-cognates. Within the broader context of this thesis, this chapter highlights how computational tools can complement theoretical and empirical research. Its findings demonstrate that the cognate facilitation effect can, in principle, be explained by the statistical learning mechanisms inherent in these models. This chapter was published as Winther, Matussevych, and Pickering (2021) in the *43rd Proceedings of the Annual Meeting of the Cognitive Science Society*.

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## 3.1 Introduction

Cognates are words that share form and meaning across languages, like the noun *winter*, which has identical orthography and meaning in English and Dutch.<sup>1</sup> Cognates are widely studied in bilingual language comprehension and production as they may be central to our understanding of bilingual lexical access (Costa et al., 2000). One consistent finding about cognates is that bilingual speakers process them faster than non-cognates (and than monolingual speakers do), known as the *cognate facilitation effect*. This effect has been reported across various experimental tasks, including sentence processing (Costa et al., 2000; Dijkstra et al., 1999; Libben & Titone, 2009; Schwartz & Kroll, 2006, etc.). For instance, Dutch–English bilinguals read the English example (1) faster with the cognate word *winter* than with the control word *prison* (*gevangenis* in Dutch), even though the two words are matched on their English corpus frequencies (Bultena et al., 2014).

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<sup>1</sup>Cognates can be spelled with small differences across languages, but here we focus on identical cognates.

- (1) The residents dislike the [*winter* / *prison*] ...  
cognate control

The exact nature of the facilitation effect, however, is not known. One open question is whether it is driven by the higher cumulative frequency of cognates compared to non-cognates (Midgley et al., 2011; Voga & Grainger, 2007): due to the identical form, Dutch–English bilinguals encounter a cognate such as *winter* more frequently than a non-cognate such as *prison*. This effectively makes cognates similar to words with very high frequency within one language. Although the cumulative frequency hypothesis has found some empirical support (Strijkers et al., 2010; Voga & Grainger, 2007), it is not universally accepted. For example, van Hell and Dijkstra (2002) argue that cognate facilitation is not just due to cumulative frequency and that cognates have a special type of representation in the mental lexicon.

The current paper investigates whether the cognate facilitation effect in sentence processing can be explained by cumulative word frequency. We use computational language modeling, a well-established paradigm in research on on-line language processing (e.g., Smith & Levy, 2013). Language models are well-suited for studying on-line processing, because they predict the next word in a sentence, and their predictions correlate with human reading times (e.g., Goodkind & Bicknell, 2018). The exact relationship between a word’s predictability in context and its (unigram) frequency is not known (e.g., Shain, 2019; Staub, 2015), but more frequent words tend to also be more predictable in neural language models (Xie et al., 2015). Importantly, such models provide full control over the input data, so that the exact frequencies of cognates and non-cognates can be counted, and they treat cognates and non-cognates in exactly the same way, without assigning cognates any special status. This makes computational language modeling a suitable paradigm to test the cumulative frequency hypothesis.

We train the model on two (Dutch–English, Norwegian–English) languages and test it on stimuli from two experiments on the reading of identical cognates in English sentence contexts, carried out with corresponding bilingual populations (Bultena et al., 2014; Winther, 2017). The sentence contexts contain a target word which is either a cognate or a non-cognate (control) word, as in (1) above. Because the Dutch–English cognate *winter* occurs in both languages, a model trained on Dutch and English will encounter this word overall more frequently than the control word, *prison*. If our model predicts cognates to be more likely than non-cognates in the same sentence context, this would support the cumulative frequency hypothesis. We consider multiple model variants, trained under different conditions of input data presentation, through manipulating

three variables: first language (L1) pretraining, inter-sentential language mixing in the input, and first-to-second language (L1:L2) input ratio. These manipulations change the cumulative frequencies of cognate and control words and allow us to investigate under which conditions, if any, the cognate facilitation effect is observed in the model.

Our main contribution in this study is a test of the cumulative frequency hypothesis using a computational language model trained on two languages, which we evaluate against human experimental data with Dutch–English and Norwegian–English bilinguals (Bultena et al., 2014; Winther, 2017). We show that the model can predict the cognate facilitation effect observed in human data. Our cumulative frequency analysis confirms that frequency explains the model’s predictions better than the words’ cognate status alone. We also find that the size of the cognate effect in the model depends on its linguistic accuracy.

## **3.2 Background**

### **3.2.1 Cognate Facilitation Effect**

A cognate facilitation effect in sentence processing has been observed across many language pairs (e.g., Bultena et al., 2014; Libben & Titone, 2009; Schwartz & Kroll, 2006). Here, we focus on Dutch–English and Norwegian–English, due to the availability of human experimental data with identical cognates. Specifically, we evaluate our model on the stimuli from two studies on cognate processing in second language (L2) sentence contexts by Dutch–English (Bultena et al., 2014, henceforth B14) and Norwegian–English bilinguals (Winther, 2017, henceforth W17). In both studies, bilingual participants read L2 English sentences containing either cognates or non-cognates (matched on their English frequency) whilst their eye movements were measured. Shorter reading times were observed for cognates than for control words.

### **3.2.2 Language Modeling and Bilingualism**

In research on monolingual on-line sentence processing, language models are commonly used to study a variety of phenomena (e.g., Arehalli & Linzen, 2020; Gulordava et al., 2018). In the computational study of bilingualism, to our knowledge, only Frank (2014) and Frank et al. (2016) trained such models on natural language data from two languages at the same time (see also Frank, 2021). These two studies found a significant

**Table 3.1.** Number of sentences and tokens in the training corpora.

	Sentences (mln.)		Tokens (mln.)	
	All languages	Norw.	Dutch	English
Train	1.6	28.2	29.0	42.5
Validation	0.2	3.5	3.6	5.3
Test	0.2	3.5	3.6	5.3
Total	2.0	35.2	36.3	53.1

*Note.* The corpora are matched on number of sentences.

correlation between the bilingual model’s predictions and reading times of L1 Dutch and L2 English sentences by Dutch–English bilinguals.

While it is common to compare various language model architectures on how well they predict human data (e.g., Futrell et al., 2019), we are interested to test whether the cognate facilitation effect can be predicted by *any* language model trained on two languages. We choose to use a long short-term memory (LSTM; Hochreiter & Schmidhuber, 1997) model, because it has been commonly used in on-line processing studies mentioned above and is arguably a cognitively plausible model (Merx & Frank, 2020).

### 3.3 Methods

Our general approach is to train the model on data from one or two languages and evaluate its linguistic accuracy and its ability to predict the data from the two experimental studies with cognates, B14 and W17.

#### 3.3.1 Training Data

To simulate L1 input, we use two corpora created from Dutch and Norwegian Wikipedia. For L2 input, we use an existing English Wikipedia corpus (Gulordava et al., 2018). We follow standard practices for data preprocessing: limit the vocabulary to the 50k most frequent words for each corpus, replace the remaining tokens with the unknown symbol, and exclude sentences with more than 5% unknown tokens. Each preprocessed

corpus is divided into the standard 80/10/10 split for training, validation and test sets. The corpus statistics are set out in Table 3.1.

### 3.3.2 Model

We use an LSTM language model, namely the baseline implementation of van Schijndel and Linzen (2018b)<sup>2</sup>, adopting their architecture and hyperparameters: two hidden layers (650 units each), with 650-dimensional word embeddings, a learning rate of 20, a dropout rate of 0.2 and a batch size of 128. The models are trained for 30 epochs (without early stopping) and are tested every 10 epochs, unless specified otherwise.

The model’s task is to predict the next word  $w_i$  given its preceding context, which yields a probability distribution  $P(w_i|w_1\dots w_{i-1})$ . The model’s performance is measured by perplexity, the inverse probability of the (unseen) test data:

$$PPL = \left( \prod_{i=1}^N P(w_i|w_1\dots w_{i-1}) \right)^{-\frac{1}{N}} \quad (3.1)$$

where  $N$  is the total number of tokens in the test set. Lower perplexity indicates a higher probability assigned to the test data, i.e., a better fit of the language model to the test data.

### 3.3.3 Model Evaluation

To estimate whether our model successfully learns two languages, we first report the model’s perplexity on the Wikipedia test data. This indicates the model’s overall linguistic accuracy, i.e., its ability to predict the following word in natural language sentences.

Our main goal is to determine under which conditions, if any, the bilingual model displays a cognate effect. For this, we use surprisal ( $S$ ), a commonly used measure thought to reflect the cognitive effort of processing a word in a given context (Hale, 2001; Smith & Levy, 2013):

$$S(w_i) = -\log_2 P(w_i|w_1\dots w_{i-1}) \quad (3.2)$$

We expect the model to display lower surprisal values for cognates than their controls on two sets of test stimuli: 21 pairs of B14’s noun sentence stimuli and 28 pairs of

<sup>2</sup><https://github.com/vansky/neural-complexity>. Tokenisation was at the word level. Note that van Schijndel and Linzen (2018b) trained the model for 40 epochs, but we stop after 30 epochs due to very small improvements after that.

**Table 3.2.** Log-frequencies of each word type per L1:L2 training condition.

	English		50:50		75:25	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<b>B14 (Dutch–English data)</b>						
Cognate	3.32	0.56	3.18	0.54	3.08	0.55
Control	3.05	0.69	2.75	0.71	2.43	0.77
<b>W17 (Norwegian–English data)</b>						
Cognate	2.85	0.65	2.64	0.64	2.46	0.64
Control	2.79	0.51	2.50	0.52	2.20	0.53

*Note.* *M* and *SD* represent mean and standard deviation, respectively.

W17’s semantically constraining sentences. We also measure the size of the cognate effect for a given pair of words as the difference in surprisal values: a greater difference between the control and the cognate words occurring in the same context indicates a larger effect size:

$$\Delta S(w_i) = S_{\text{control}_i} - S_{\text{cognate}_i} \quad (3.3)$$

In all the statistical analyses, we use mixed-effects models, as implemented in *lme4* package (Bates et al., 2015) for *R* (R Core Team, 2020).

## 3.4 Simulations

Using the described architecture and data sets, we train monolingual and bilingual models under different conditions of input presentation, as described below. Each model is trained with 5 different random seeds (i.e., initializations of model weights) to ensure the results are robust. We evaluate the models on linguistic accuracy and their ability to predict the cognate facilitation effect observed in B14 and W17.

### 3.4.1 Monolingual Models

We first train monolingual models on each of the three languages independently: English, Dutch, and Norwegian. We report each model’s linguistic accuracy (perplexity) on the test set for the respective language. These are used as monolingual points of comparison to evaluate the performance of the bilingual models.

**Table 3.3.** Characteristics of the six bilingual models.

Model	Variables			Type of bilinguals	
	L1 pretr.	Lang. mix.	L1:L2 ratio	Unbal./ balanc.	Simult./ sequen.
PT-MX-50	+	+	50:50	Un-/Bal.	Sequen.
PT-MX-25	+	+	75:25	Unbal.	Sequen.
NPT-NMX-50	–	–	50:50	Balanc.	Sequen.
NPT-NMX-25	–	–	75:25	Unbal.	Sequen.
NPT-MX-50	–	+	50:50	Balanc.	Simult.
NPT-MX-25	–	+	75:25	Unbal.	Simult.

### 3.4.2 Bilingual Models

The bilingual models are trained on samples from two languages' data, keeping the total number of sentences constant. The vocabulary for the bilingual models is the unified vocabulary for the L1 and L2 corpora. There are various ways to train the model on two languages, depending on the relative amount of training data in each language and the order of presentation. We explore these differences by manipulating three variables:

1. **L1 pretraining.** We consider models with pretraining (pretrained, PT) and without pretraining (non-pretrained, NPT). NPT models are trained on data from two languages in parallel. PT models are first trained on the L1 data for 30 epochs and then on combined bilingual data for 10 more epochs. Unlike NPT models, PT models are saved for further testing after every epoch during bilingual training.
2. **Language mixing.** Within each training epoch, we either present the model with L1 data followed by L2 data (non-mixed models, NMX), or with randomly shuffled combined L1–L2 sentences (mixed models, MX).
3. **L1:L2 ratio.** We combine either 75% of the L1 and 25% of the L2 corpora, or 50% each. These proportions are arbitrary, as our aim is to compare models trained on different and equal proportions of L1:L2. Manipulating this ratio changes the cumulative frequencies of English cognates and control words in the training data, as shown in Table 3.2.

The 3 variables with 2 values each result in 8 bilingual models. We do not consider the 2 pretrained non-mixed models, because our preliminary simulations showed that a

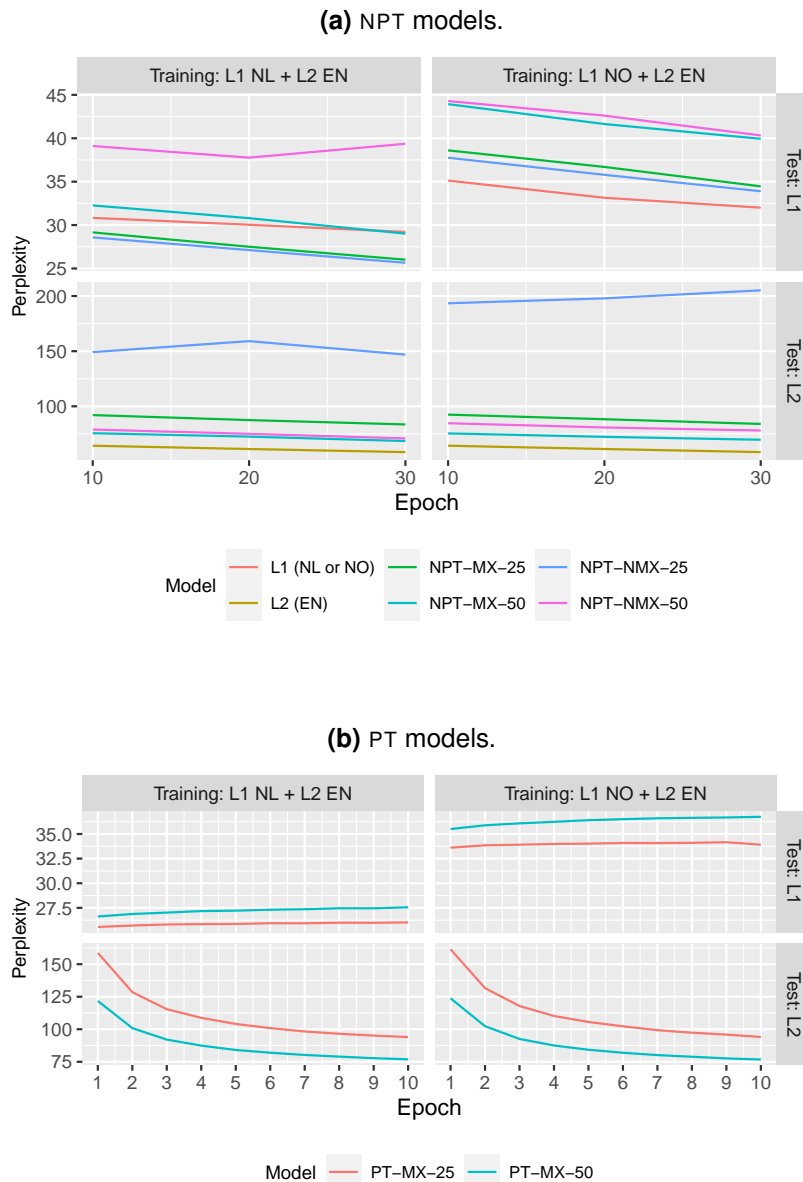
model cannot learn L2 from non-mixed input if its exposure to L1 is much higher than to L2. This leaves us with 6 bilingual models. We use the values of the 3 variables above to refer to each model: e.g., PT-MX-25 is a pretrained mixed model with 25% L2 in the bilingual part of its training data. Table 3.3 shows the characteristics of all 6 models and how they can be related to various types of bilingualism: *unbalanced* bilingualism (larger exposure to L1 than to L2) vs. *balanced* bilingualism (approximately equal exposure), and *simultaneous* bilingualism (both languages are acquired from birth) vs. *sequential* bilingualism (learning an L2 later in life). Note that the mapping between model variants and types of bilinguals is approximate: e.g., PT-MX-50 sees equal amounts of L1 and L2 in the bilingual data, yet overall it is exposed to more L1 due to pretraining.

## 3.5 Results

We are primarily interested in whether the bilingual models exhibit the cognate effect and under which conditions. First, however, we present the models' overall linguistic accuracy. All results are averaged over 5 random initializations.

### 3.5.1 Models' Linguistic Accuracy

We first look at the overall linguistic accuracy of each bilingual model in comparison to the monolingual models, to see how well the bilingual models learn two languages. The models' perplexity over time is shown in Figure 3.1. Note that the values cannot be compared across panels, as the test sets are different (except the L2 English test set), and the absolute perplexity values vary substantially across languages (Gerz et al., 2018). We observe similar patterns in each of the two language pairs. First, L1 test perplexity is low ( $< 45$ ) and stable across training epochs for all models (top panels in each subplot), indicating that L1 learning is successful and that L2 learning does not jeopardize L1 linguistic accuracy. Second, the L2 English perplexity for most of the bilingual models is only somewhat higher than for the monolingual English model (bottom panels in Figure 3.1a). One exception is NPT-NMX-25, which has high ( $> 145$ ) perplexity on the L2 test set compared to all other models ( $< 100$ ) and does not improve over time. This suggests that when a model is exposed predominantly to one language (L1) *and* sees that language first within each epoch, it cannot achieve high linguistic accuracy in the other language (L2), an issue we return to in the discussion. Lastly, all



**Figure 3.1.** Mean model perplexities for (a) non-pretrained (NPT) and (b) pretrained (PT) models, on the L1 Dutch (NL) or Norwegian (NO), or L2 English (EN) Wikipedia test sets.

-25 models have lower L1 perplexity, but higher L2 perplexity than the corresponding -50 models: accuracy in a given language increases with its share in the training data. To summarize, our model displays general learning patterns that are consistent with the conditions of L1 and L2 input data presentation, depending on our use of this model for the study of bilingualism.

### 3.5.2 Cognate Facilitation Effect in the Model

Here, we analyse the relationship between words' cognate status and models' surprisal values, to see if the models display the cognate facilitation effect. We expect surprisal for cognates to be lower than for control words. We fit a mixed-effects linear regression to the surprisal values predicted by each bilingual model variant (and the monolingual model, as a sanity check). Fixed effects include cognate status (cognate vs. control), epoch (to account for the model's learning over time), and their interaction. Random effects include intercepts for model's random initialization, item, and sentence context.<sup>3</sup>

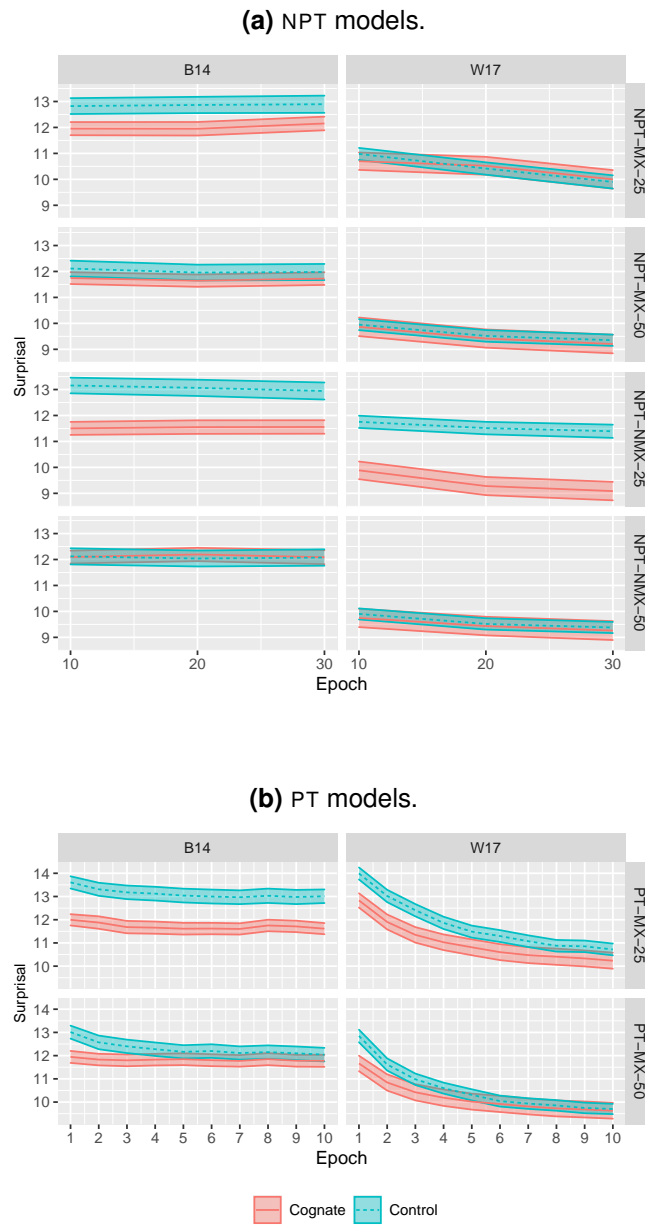
As a simple check, we first consider the monolingual English model. Because the frequencies of cognates and control words are matched in English, we expect no cognate effect. Indeed, the model shows no significant effect: the regression coefficients ( $b = 0.01$  and  $0.08$ ,  $|t| = 0.02$  and  $0.11$  for B14 and W17, respectively) suggest no meaningful differences between the surprisal values for cognates vs. control words.

The surprisal values for bilingual models are shown in Figure 3.2. We first look at the four NPT models (Figure 3.2a). For both language pairs, a significant effect of cognate status is only observed for NPT-NMX-25 (note the gaps between the pairs of lines):  $b = -1.79$  and  $-1.70$  ( $|t| = 2.30$  and  $2.34$ ) on B14 and W17, respectively, meaning lower surprisal values for cognates than for control words. Additional by-epoch analyses for this model variant confirmed the presence of the cognate facilitation effect at each time point for both data sets, except at epoch 30 on the B14 stimuli.

Next, we look at the two PT models (Figure 3.2b). We observe a significant effect of cognate status for PT-MX-25 on both data sets:  $b = -1.56$  and  $-1.23$  ( $|t| = 2.37$  and  $2.03$ ), again suggesting lower surprisal values for cognates than for control words. We also observe significant positive interactions between cognate status and epoch for both PT-MX-25 and PT-MX-50 on both data sets, suggesting that the difference between control and cognate words gets smaller with more training (the gap between the pairs of lines in Figure 3.2b decreases over time). Again, our by-epoch analyses show that on the B14 stimuli the cognate effect was significant for most epochs of the PT-MX-25 model (but not at all for the PT-MX-50 model). On the W17 stimuli, the effect was significant only at epoch 1 for both PT-MX-25 and PT-MX-50.

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<sup>3</sup>Full mixed-effects model structure in  $R$ :  $\text{surprisal} \sim \text{cognate\_status} * \text{epoch} + (1|\text{word}) + (1|\text{sentence}) + (1|\text{initialization})$ . Random slopes could not be included due to convergence issues. Some random intercepts were excluded to ensure model convergence: random initialization for NPT-MX-50, random initialization and sentence for the English model.



**Figure 3.2.** Mean model surprisal values for cognates and control words from B14 and W17. Ribbons indicate standard error. Note that the absolute surprisal values on B14 vs. W17 cannot be compared, because the test data sets are different.

### 3.5.3 Cumulative Frequency Analysis

We have observed a consistent cognate facilitation effect in two of our bilingual models: NPT-NMX-25 and PT-MX-25. Because our models treat cognates and control words in the same way, this effect must be attributed to the different cumulative frequencies

of the two types of words in the training data. If that is the case, a word’s frequency must predict its surprisal value better than the cognate status does. To test this, we again consider the surprisal values of NPT-NMX-25 and PT-MX-25 on B14 and W17. Just as before, we fit four mixed-effects regressions to these values, but this time including cumulative word frequency as an additional predictor variable.<sup>4</sup> The regression analyses show that word frequency is a significant predictor of surprisal for both language models on both B14 and W17, while cognate status is no longer significant in these new regressions. For NPT-NMX-25 tested on B14 and W17, the regression coefficients for frequency are  $b = -2.43$  and  $-3.42$  ( $|t| = 4.68$  and  $5.65$ ), and for cognate status  $b = -0.22$  and  $-0.81$  ( $|t| = 0.30$  and  $1.15$ ). Analogously, for PT-MX-25,  $b = -2.32$  and  $-3.67$  ( $|t| = 4.96$  and  $6.77$ ) for frequency, and  $b = 0.97$  and  $0.96$  ( $|t| = 1.28$  and  $1.53$ ) for cognate status. This confirms that cumulative frequency explains the cognate facilitation effect in our models.

### 3.5.4 Linguistic Accuracy and the Cognate Effect

We have found that cumulative word frequency can predict surprisal in our two bilingual language models that show the cognate facilitation effect. Yet, frequency alone cannot determine the presence of the effect in a given model. Consider two models trained on the same data under different conditions, NPT-NMX-25 and NPT-MX-25. Despite identical word frequencies, only the former displays a cognate effect. We know that these two models differ in their linguistic accuracy, and here we ask whether a model’s linguistic accuracy (measured by perplexity) can predict the size of the cognate effect in that model. We consider by-epoch perplexity values for each of our six bilingual models and test whether perplexity can predict the size of the cognate effect (measured as  $\Delta S$ , see Equation 3.3) at a given training time for a given model. To do so, we fit a series of mixed-effect regressions with  $\Delta S$  as the dependent variable, L2 (English) perplexity and epoch (with their interaction term) as the fixed effects, and random intercepts over sentence pair and random initialization. As before, we run separate analyses for NPT and PT models. For both types of models, L2 perplexity is a significant predictor of  $\Delta S$  on both data sets. For NPT models,  $b = 0.02$  and  $0.02$  ( $|t| = 5.26$  and  $6.22$ ) on B14 and W17, respectively. For PT models, the respective values are:  $b = 0.01$  and  $0.01$  ( $|t| = 4.28$  and  $3.43$ ). This suggests that the cognate effect is observed in the models

<sup>4</sup>For NPT models, we use a word’s total frequency in each bilingual training sample. For PT models, we compute the total number of times each word is seen during training:  $F(w)_{L1} \times 30 + F(w)_{\text{biling.}} \times 10$  (where 30 and 10 are the number of L1 pretraining and bilingual training epochs, respectively).

with higher L2 perplexity, or lower L2 linguistic accuracy.

### 3.6 Discussion

Our main goal was to test whether the cognate facilitation effect in bilingual speakers can be explained by cumulative word frequency. To do this, we trained computational language models on two languages (Dutch–English or Norwegian–English). We manipulated three variables determining the patterns of input data presentation to the model — L1 pretraining, language mixing, and L1:L2 ratio — to explore a number of model variants. We tested each variant on the stimuli from sentence reading experiments with bilingual speakers (Bultena et al., 2014; Winther, 2017), and analyzed the models’ predictions for cognate vs. control words. We observed a significant cognate effect for two (out of six) model variants across both language pairs. Because our model does not process cognates differently from other words, the effect observed in our models cannot be explained by cognates’ special status, as suggested by van Hell and Dijkstra (2002). Instead, we found that a word’s frequency predicts its surprisal value better than its cognate status does. This finding supports the cumulative frequency hypothesis: the higher frequency of cognates (compared to non-cognates) facilitates their processing in sentences. At the same time, we did not test a similar computational model that would explicitly assign cognates a special status, and we cannot argue against van Hell and Dijkstra’s proposal based on our result. While further research is needed in this respect, we have shown that the cumulative frequency hypothesis *can* in principle explain the cognate effect.

The common properties of the two model variants that displayed the cognate effect are their higher exposure to L1 than to L2 and the presentation of L1 before L2. Both of these characteristics are associated with lower linguistic accuracy in L2, and our analysis of accuracy confirms that the models’ L2 accuracy can predict the size of the cognate effect. Therefore, language accuracy (or “proficiency”) also affects the presence of the cognate effect in a given bilingual model. This mirrors the trend found in bilingual speakers: the cognate effect is stronger in less proficient L2 speakers (Bultena et al., 2014; Libben & Titone, 2009; Pivneva et al., 2014). Therefore, the effect could be due to the lack of exposure to non-cognate words. In less proficient speakers, cognate words behave like high-frequency words do in a monolingual setting, while their control words (matched on L2 frequency) function like lower-frequency words. With increased proficiency, the differences in exposure to the two types of words become smaller,

leading to smaller cognate effects.

Based on the finding that the cognate effect in our model is observed only when the model's exposure to L2 (relative to L1) is low, one could argue that in our case the effect is just an artefact. However, it is important to note the differences in the amount of data required for successful learning in humans vs. neural language models. As pointed out by, e.g., Linzen (2020), compared to models such as the one used in this study, humans learn language from considerably less exposure. Therefore, further research is required to reveal the exact relationship between language exposure, the learning of two languages, and the presence of a cognate effect in both humans and models. In particular, the dynamics of bilingual learning and forgetting in neural language models are not the same as in human speakers, and one challenge is to better understand under which conditions of L1 and L2 exposure the model can successfully learn both languages, and how these conditions differ from what we know about bilingual learning in human speakers. Here we have made first steps in this direction. For example, we showed that with low L2 exposure the order of L1–L2 presentation within each training epoch has a strong effect on the model's L2 proficiency, to the extent that models pretrained on L1 may be unable to learn L2 if it comes after L1 in each epoch. This result, which may seem anomalous from the cognitive perspective, helps us better understand how the model's variables such as pretraining, language mixing and L1:L2 ratio map onto L2 learning settings in human speakers.

Our approach and findings align with Frank's (2021) desiderata (such as parsimony) for useful models of bilingual sentence processing. We argue that computational language models can be used to address open questions in this domain. Despite the mentioned challenges, such models can be theoretically appropriate for drawing conclusions about whether specific effects in bilingual cognition can be explained by learning mechanisms implemented in such models, and under which conditions.



## Chapter 4

# Is Cognate Processing Affected by the Language of Instruction?

Multilinguals process cognates faster than non-cognates. This cognate facilitation effect is typically explained by the on-line co-activation of lexical representations across languages, which boosts activation for cognates, a process which does not occur for non-cognates (e.g., Dijkstra & van Heuven, 2002). However, a different explanation suggests that the salient form overlap of cognates increases cross-language activation during learning, resulting in more “enhanced” representations for cognates than non-cognates (Costa et al., 2017). To better understand whether co-activation during learning contributes to cognate effects, we consider the effect of the language of instruction on cognate processing in 88 trilinguals (Dutch–French–English and French–Dutch–English), half of whom learned a third language (L3) English through Dutch education and half through French education. We hypothesised that co-activation is more likely to occur when learning cognates between the L3 and the language of instruction than when cognates between the L3 and another known language are learned, because form overlap is more salient for cognates between languages used during learning. Therefore, we expected facilitation for the former and not the latter type of cognates. Participants performed a lexical decision task in L3 English that included Dutch–English and French–English cognates, as well as matched non-cognates. Confirming our prediction, participants responded faster to words that were cognates between the target language and the language of instruction than cognates with the participants’ other known language. Our findings lend support to the hypothesis that learning mechanisms may contribute to the facilitated processing of cognates.

## Foreword

This chapter builds on the theoretical framework established in Chapters 1 and 2, as well as the computational exploration of cognate facilitation presented in Chapter 3. While Chapter 3 demonstrated that cognate effects can, in principle, be explained by statistical learning mechanisms, this chapter takes an empirical approach to investigate the role of learning in cognate processing. Extending the discussion in Chapter 2 about learning-based versus on-line explanations of cognate effects, this chapter explores whether co-activation during learning contributes to the facilitation of cognates, as opposed to the commonly assumed explanation that on-line co-activation during processing is the main driver of the effect. The findings presented here complement the theoretical contributions of Chapter 2 and advance the broader aim of this thesis by further disentangling the roles of learning and on-line processing mechanisms in bilingual and multilingual language comprehension.

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## 4.1 Introduction

In the study of multilingual lexical processing, cognate words are special because they have the same or similar spelling and pronunciation, as well as the same meaning in different languages. For example, the Dutch word *winter* is cognate with its English translation equivalent *winter*. Cognates have been extensively studied to better understand the process of lexical access in bilinguals, as they could shed light on whether and how representations from both languages are activated during word retrieval.

Previous research has primarily focused on differences in processing between cognates and non-cognates (i.e., translation equivalents that do not share form features). These studies have found a processing advantage for cognates relative to matched non-cognate control words. This *cognate facilitation effect* has been observed across different language pairs and psycholinguistic tasks. For instance, in second language (L2) comprehension, it has been found that lexical decision and reading times of cognates with orthographic overlap are usually faster than those of non-cognates (e.g.,

Dijkstra et al., 1999; Duyck et al., 2007; Libben & Titone, 2009). However, this facilitation can be modulated by factors such as the degree of form overlap (e.g., Duyck et al., 2007; Tiffin-Richards, 2024), sentence context (see e.g., Lauro & Schwartz, 2017, for a meta-analysis), or task demands such as whether both languages are used in the task (Poort & Rodd, 2017; Poort et al., 2016). Several studies have also demonstrated a learning advantage for cognates in both L2 and L3<sup>1</sup> learning, indicating that they are learned faster and retained better in memory compared to non-cognates (both in children and in adults: de Groot & Keijzer, 2000; de Vos et al., 2019; Elias & Degani, 2022; Hirosh & Degani, 2021; Lotto & de Groot, 1998; Marecka et al., 2021; Otwinowska & Szewczyk, 2019; Salomé et al., 2022; Tonzar et al., 2009). These studies demonstrate that language learners benefit from the formal cross-linguistic similarity of cognates during learning.

There have been different explanations as to why cognates have an advantage in processing. One explanation assumes that lexical representations are activated non-selectively across languages during bilingual lexical access, as is the assumption of models of written word recognition, such as the BIA+ (Dijkstra & van Heuven, 2002) and MULTILINK models (Dijkstra et al., 2019). According to these models, if for instance a Dutch–English bilingual reads a cognate word, such as the English *winter*, the orthographic representations for both the English WINTER and Dutch WINTER are activated. This non-selective co-activation of both target and non-target language form representations is then assumed to converge on the level of semantics when the word’s meaning is retrieved, after which the activation feeds back to the orthographic level. Thus, the activation of lexical representations for cognates stems from two sources rather than one, as is the case with non-cognates. This leads to a difference in activation levels between the two word types, with lexical retrieval being faster for cognates because of higher levels of activation. Although this hypothesis has been widely accepted in the literature, it provides limited insights into the role of learning in relation to cognate processing. In this paper, we ask whether the processing differences observed between cognates and non-cognates could be explained by learning.

Many authors have previously suggested that the manner in which cognates are learned may contribute to their facilitated processing, with the idea being that cognates have qualitatively different representations in memory compared to non-cognates (e.g., de Groot, 2010). For instance, in an account put forward by Costa et al. (2017), the

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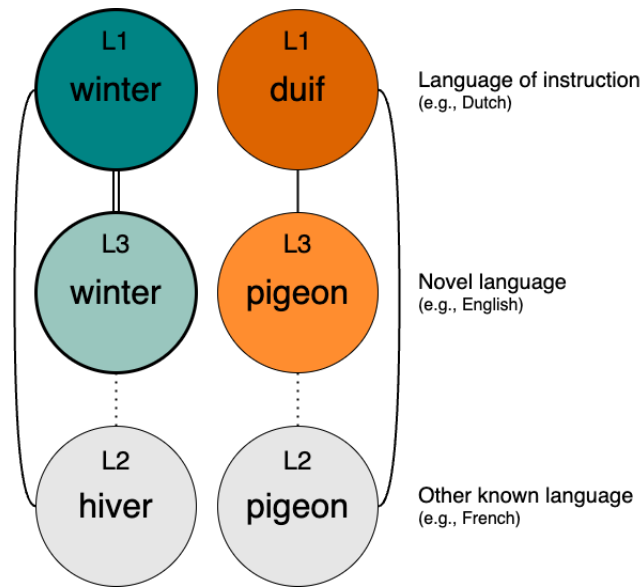
<sup>1</sup>Following Ecker and García Mayo (2015), we use the term L3 to refer to a language learned by someone who already has knowledge of two languages.

mechanisms that lead to the representational differences of cognates is that activation spreads between related representations (spreading activation) and co-activated representations develop a connection (Hebbian learning). Crucially, the co-activation of representations between languages may occur during initial acquisition of a novel language, but may be reduced with increased proficiency as between-language connections in the newly acquired language become more developed. The form similarity between the translation equivalents of cognates leads to stronger co-activation during learning, resulting in more “enhanced” representations in lexical memory for cognates relative to non-cognates, similarly to how higher frequency words are assumed to be more accessible in memory compared to lower frequency words. Consequently, co-activation gives cognates a learning advantage, which in turn leads to their processing advantage, as they require less evidence to reach the threshold for successful recognition.

#### 4.1.1 The Current Study

In the current study, we explore the role of the language of instruction (i.e., the language through which an L3 is acquired) in trilingual cognate processing to better understand the role of learning in relation to cognate effects. Our hypothesis is that co-activation of lexical representations may be stronger between the L3 and the language of instruction, than between the L3 and another known language not used during learning (henceforth the L2), and that this affects how lexical representations in the L3 are formed. We ask whether the degree of co-activation may affect how cognates are represented in the mental lexicon, and in turn, their processing.

For instance, if a Dutch–French bilingual learns the Dutch–English cognate *winter* (*hiver* in French) in English with the language of instruction being Dutch, a special link is created through the process of Hebbian learning between the lemmas of the new word *winter* and its Dutch source word *winter* because their form overlap is salient. The question is whether such a link is created between the lemmas of the new word and its French source word *hiver* if French is not involved in the learning process. Similarly, when a French–English cognate, such as *pigeon* (*duif* in Dutch), is learned, the form overlap is less salient because learning is not mediated through French. Consequently, no special links or representations are assumed to be established for these types of cognates. The established connections between the lexical representations are visualised in Figure 4.1. Because co-activation of lexical representations is stronger for the former than latter type of cognates, a stronger link or more enhanced representations should be



**Figure 4.1.** Example of connections between lexical representations formed by learning in Dutch–French bilinguals acquiring English through Dutch. Lexical representations are shown of a cognate between a novel language and the language of instruction (Dutch–English cognate; green) and a cognate between the novel language and another known language (French–English cognate, Dutch–English non-cognate; orange) in the language of instruction (Dutch; top), novel language (English; middle), and other known language (French; bottom). Thickness of lines indicate connection/representation strength.

formed for their lexical representations. As such, processing differences, in terms of the size of the cognate effect, should be observed between the two types of cognates, and cognate facilitation should depend on the language of instruction.<sup>2</sup>

Alternatively, it could be that cognate learning utilises form similarities from any existing lexical representations. In this case, our Dutch–French bilingual learner would benefit from form overlap of cognates between English and Dutch but also between English and French, even if Dutch is the language of instruction. Evidence for this hypothesis comes from for instance Bartolotti and Marian (2017), who conducted an experiment where English–German bilinguals learned an artificial language through pictures. The novel words were either similar to English, German, both languages, or neither language, in terms of word similarity measures such as orthographic neighbourhood size and orthotactic probability. Lexical similarity to either language (and in

<sup>2</sup>Although such an account allows for a role of learning in explaining cognate effects, it does not rule out that the effect occurs due to co-activation on-line during processing (for instance occurring via the links between the words).

particular the native language (L1)) was sufficient to facilitate learning (as measured by reaction times (RTs) and accuracy in written word recognition and production), with no additional benefit from cumulative wordlikeness to both languages. They explain their findings in terms of the scaffolding model, where the learning of individual words may benefit from transfer from either of the existing languages, and suggest that early L3 word learning involves ‘linking novel words to anchors in a single language’ (2017, p. 129).<sup>3</sup> However, as the learning method was picture-mediated learning, and the participants differed in terms of their L1, it is unclear whether their results would be different if the language of instruction was manipulated (i.e., whether the artificial language was learned through English or German).

To investigate whether the language of instruction modulates cognate facilitation, we set up a web-based lexical decision experiment (LDT) with trilinguals fluent in Dutch, French, and English. Two groups of trilinguals were recruited for the experiment: one group that learned L3 English through Dutch education (henceforth Dutch-LOI group) and a second group who learned L3 English in French education (henceforth French-LOI group). To determine whether the language of instruction affects how cognates are learned and processed, we measured lexical decision times and error rates to Dutch–English and French–English cognates and matched non-cognate control words in the L3 English. Our research question is whether there is an interaction between cognate status (cognate vs. non-cognate), the cognate language (Dutch–English vs. French–English), and participants’ language of instruction (Dutch vs. French). If the Dutch-LOI group show a cognate facilitation effect for Dutch–English but not French–English cognates, and similarly, if the French-LOI group show facilitation for French–English and not Dutch–English cognates, it suggests that the language of instruction may influence how cognates are learned and subsequently processed. If cognate effects are observed for both types of cognates, it suggests that form similarities can lead to transfer from and/or co-activation of lexical representations in any existing languages.

Below, we first review studies that have investigated the role of form similarities and the language of instruction in L3 word learning, before we outline findings from cognate processing in L3 comprehension.

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<sup>3</sup>It is important to note that the authors do not specify whether the language of instruction would play a role in the establishment of these links within the scaffolding model.

### 4.1.2 The Role of Form Similarities and the Language of Instruction in L3 Word Learning and Processing

The role of (form) similarities in vocabulary acquisition has been explored in various studies, highlighting how such similarities can facilitate the learning process. Our hypothesis, based on Costa et al.'s (2017) account, suggests that cognates between an L3 and a language not involved in the learning process, should not elicit cognate effects in learning or processing. Alternatively, form similarities from any existing lexical representations may contribute to the enhanced learning and processing of cognates, as per the scaffolding model of Bartolotti and Marian (2017), meaning that the cognate advantage may also be observed for cognates between the L3 and any other known languages.

Hirosh and Degani (2021) examined the influence of the language of instruction on L3 word learning. In their study, adult Hebrew–English bilinguals were tasked with learning L3 German words that were cognate or non-cognate with their L2 English translations. The language of instruction was manipulated such that half the participants learned the words through their L1 Hebrew, and the other half through L2 English. The to-be-learned words were presented auditorily along with their written translation equivalents in the language of instruction. The study found a significant cognate effect on error rates and RTs in translation recognition and production, with cognates eliciting fewer errors and shorter RTs than non-cognates. Interestingly, no significant interaction was observed between cognate status and the language of instruction, suggesting that the learning of L2–L3 cognates was similar regardless of whether the L1 or L2 was the language of instruction, and whether the cognates' translation equivalents were present during learning.

Hirosh and Degani's findings indicate that, at least in the early stages of learning, cognate similarities to both languages may facilitate learning, lending support to Bartolotti and Marian's (2017) scaffolding model. However, as pointed out by the authors, the power to detect an interaction (with an effect size of Cohen's  $d = 0.3$ ) between the language of instruction and word type was relatively low (0.531) with their experimental set-up. As a result, the possibility remains that cognates between the two languages involved in learning may be learned better.

Similar findings were reported by Lijewska and Błaszowska (2021), who investigated whether the language of instruction modulates the cognate effect in processing with a verbal translation task. Here, Polish–German–English trilinguals, who learnt L3

English and L2 German via L1 Polish performed a verbal translation task, translating Polish–English (L1–L3) and German–English (L2–L3) cognates and controls from L3 English to L1 Polish and to L2 German. Their results converge with those of Hirosh and Degani (2021): translation of cognates was more accurate than that of non-cognates, and this was not modulated by the cognate language (German–English vs. Polish–English) or translation direction. The authors conclude that the language of instruction does not modulate the effect. However, as the authors themselves point out, many of their participants commented that they found translation into L2 German difficult, and that they ‘mentally translated first into Polish and then into German’ (2021, p. 344). This strategy, in addition to the fact that both the task (translation) and the procedure (translation into both L1 and L2 in separate blocks) involve a three-language mode, which would activate all the languages and may explain why both types of cognates were facilitated.

In the two above-mentioned experiments, cognate facilitation was measured using a translation task, which allows for more time for cross-linguistic effects to emerge, in contrast to speeded tasks like lexical decision. Lemhöfer et al. (2004) conducted a lexical decision experiment with Dutch–English–German trilinguals. Participants were shown L3 German words that were cognates between their L3 German and L1 Dutch, triple cognates between German, Dutch and English, or non-cognates between all three languages. They observed significant facilitation in RTs for triple cognates compared to L1–L3 cognates and for L1–L3 cognates relative to non-cognates. They argued for a cumulative cognate effect across languages and interpreted their results as the simultaneous activation of all three languages during L3 word recognition. This view is, according to the authors, compatible with a parallel activation account, where converging activation between the form level and semantic level accounts for the effect, or a learning account (de Groot & Keijzer, 2000) where the cumulative frequencies of cognates explain the results.

The findings of Lemhöfer and colleagues were replicated in Szubko-Sitarek (2011, Experiment 1), who measured lexical decision times on L3 German words in Polish–English–German trilinguals, and obtained cognate facilitation for both Polish–German and triple cognates, with the latter showing a larger effect. In a later experiment with the same task and population, but different stimuli, Szubko-Sitarek (2015, Experiment 4) compared RTs to L3 German words that were cognates with either L2 English or L1 Polish, or non-cognates between all three languages. Interestingly, only L1–L3 cognates and not L2–L3 cognates showed a significant difference compared to non-cognates. The author hypothesised that learning experience may be driving the observed patterns,

pointing to the participants' language of instruction being L1 Polish (with no L2 English used during the lessons). She emphasises that the nature of the learning experience may have influenced the structure of the mental lexicon, suggesting that the 'factor may be powerful enough to foster strong connections between languages extensively and concurrently used in education.' (2015, p. 166). Compatible with the account of Costa et al. (2017), the results of Lemhöfer et al. (2004) and Szubko-Sitarek (2011) can be explained by triple cognates having an even more prominent representation in the mental lexicon compared to double cognates due to co-activation during learning between the language of instruction and the language that is being learnt. When triple cognates are being learned during L3 acquisition, the representation of double cognates is further "enhanced", leading to a facilitated processing of triple cognates compared to two-language cognates.

In the present study, trilingual participants perform a non-native language LDT, where cognate effects has been most frequently replicated (Lemhöfer et al., 2004). The task is in a one-language mode (Grosjean, 1997), where the participants' other languages are not mentioned or used before or during the experiment. Previous studies have demonstrated that language context can influence cross-language effects (Wu & Thierry, 2010), and thus our study allows us to examine the contribution of the language of instruction on cognate processing in a one-language mode, without encouraging activation of the non-target languages.

## 4.2 Methods

### 4.2.1 Participants

88 Dutch–French–English trilingual participants between 18–40 years ( $M_{age} = 23.7$  years,  $SD_{age} = 5.9$ ; 62 female, 25 male, 1 prefer not to say) with no language impairments completed the experiment remotely in exchange for €5 or €7. Of these, 44 were native Dutch speakers fluent in L2 French and L3 English (Dutch-LOI group) recruited through the recruitment platform at Ghent University, Belgium and from Prolific Academic ([www.prolific.com](http://www.prolific.com)). The remaining 44 participants were native French speakers fluent in L2 Dutch and L3 English (French-LOI group), recruited via Prolific as well as contacts at French-speaking universities in Belgium (UC Louvain, University of Liège, and Université Libre de Bruxelles). All participants completed their education in Belgium. Crucially, the primary language of education (up to but not

**Table 4.1.** Descriptive statistics of participants' language experience and proficiency by group.

	Dutch <i>n</i> = 44		French <i>n</i> = 44	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Age (years)	24.2	6.4	23.2	5.3
Age of L2 acquisition (years) <sup>a</sup>	9.5	2.8	8.8	4.0
L2 Experience (years) <sup>a</sup>	14.7	6.6	14.5	7.3
Age of L3 acquisition (years) <sup>b</sup>	11	2.9	12.8	1.8
L3 Experience (years) <sup>b</sup>	13.2	6.3	10.5	5.4
L1 usage (%)	69.9	16.3	60.9	22.9
L2 usage (%) <sup>a</sup>	9.5	12.9	15.2	14.2
L3 usage (%) <sup>b</sup>	21.3	14.6	29.7	19.4
L1 Speaking <sup>c</sup>	9.6	0.8	9.4	0.9
L1 Comprehension <sup>c</sup>	9.6	0.7	9.8	0.6
L1 Reading <sup>c</sup>	9.6	0.8	9.6	0.9
L2 Speaking <sup>ac</sup>	5.9	1.6	5.8	2.0
L2 Comprehension <sup>ac</sup>	6.8	1.7	7.2	1.8
L2 Reading <sup>ac</sup>	6.6	1.9	7.3	1.7
L3 Speaking <sup>bc</sup>	7.9	1.3	7.6	1.5
L3 Comprehension <sup>bc</sup>	6.8	1.7	8.3	1.4
L3 Reading <sup>bc</sup>	8.6	1.3	8.5	1.1
L2 LexTALE score <sup>a</sup>	55.8	5.8	69.3	7.9
L3 LexTALE score <sup>b</sup>	82.0	11.9	79.5	10.2

*Note.* *M* and *SD* represent mean and standard deviation, respectively.

<sup>a</sup>L2 = French for Dutch-LOI group and Dutch for the French-LOI group.

<sup>b</sup>L3 = English.

<sup>c</sup>Self-rated level of proficiency on a 10-point Likert scale (0 = None; 10 = Perfect).

including higher level education) was Dutch for the Dutch group, and French for the French group, meaning that the L3 English was learned either through Dutch or French because it was learned at school.

An overview of the descriptive statistics of the language proficiency and experience

of the two groups is laid out in Table 4.1. Participants who scored below 50 on the L2 proficiency test (Dutch LexTALE and LexTALE\_FR; Lemhöfer and Broersma, 2012; Brysbaert, 2013, respectively) were excluded, and new participants tested in their stead until the desired sample size was obtained. Independent samples *t*-tests showed that the two groups did not differ significantly on average self-rated L2 or L3 proficiency, age of L2 acquisition, and L3 (English) LexTALE scores (all *ps* > .153). There was a significant difference between age of L3 English acquisition, with the Dutch-LOI group starting to acquire the language slightly earlier than the French-LOI group (*p* = .001). For both groups, average self-rated L3 proficiency was significantly higher than the average L2 proficiency (paired *t*-test, both *ps* < .001). All participants had an overall lexical decision accuracy above 80% on the experimental items (*M* = 95.5%, *SD* = 4%).

### 4.2.2 Materials

Examples of the experimental stimuli can be found in Table 4.2. The experimental stimuli consisted of 144 English words. Half of these were cognates (36 Dutch–English cognates and 36 French–English cognates). The cognates were chosen from the cognate database of Schepens, Dijkstra, et al. (Dataset S1; 2013). Both the Dutch–English and French–English cognates had a normalised orthographic Levenshtein distance<sup>4</sup>  $\geq .60$  between their translation equivalents in the respective languages. Additionally, the Levenshtein distance between the Dutch and French translation equivalents of the cognates was  $\leq .40$ , to ensure that none of the words were cognates between Dutch and French.<sup>5</sup> Each cognate word was paired with a non-cognate control word, of which 55 were from the same database (Tables S2 and S3; Schepens, Dijkstra, et al., 2013). As it was not possible to find a sufficient number of matched non-cognates in the database, 17 additional non-cognate words were chosen. All controls had an orthographic Levenshtein distance  $\leq .43$  between the English–Dutch, English–French, and Dutch–French translation equivalents. Additionally, the words were checked by a native speaker of each language in order to check that they had no other cognate translations. Table 4.3 lists the descriptive statistics of all experimental stimuli. The full set of experimental stimuli can be found in Appendix A.

<sup>4</sup>Levenshtein distance was computed by Schepens, Dijkstra, et al. (2013) as  $1 - distance \div length$ , with *distance* being the minimum number of insertions, deletions and substitutions, and *length* being the maximum length of the two translation equivalents.

<sup>5</sup>With the exception of the Dutch–English cognate *winter*, which had a Levenshtein distance of .50 to its French translation *hiver*. However, the French and Dutch similarity was deemed sufficiently different for the word to be included as a Dutch–English cognate.

**Table 4.2.** Example stimuli by word type and cognate language.

Wordtype	Cognate language	
	Dutch–English	French–English
Cognate	winter ( <i>winter, hiver</i> )	pigeon ( <i>duif, pigeon</i> )
Control	garlic ( <i>knoflook, ail</i> )	monkey ( <i>aap, singe</i> )

*Note.* Dutch and French translations in parentheses.

Independent samples *t*-tests were conducted to compare cognates and their control words for each cognate language pair separately. These tests indicated that for each cognate language pair, there were no significant differences in English word length (between 4–7 letters), English Zipf frequency (SUBTLEX-UK; van Heuven et al., 2014), English concreteness (Brysbaert et al., 2014), and OLD20 (Yarkoni et al., 2008) between cognates and controls, with all  $ps > .085$ . In both cognate language pairs, cognates had a higher L1 (French or Dutch) cross-language neighbourhood density (CLEARPOND; Marian et al., 2012) than the control words ( $p = .007$  and  $p = .003$ , for the Dutch–English and French–English cognate language pairs, respectively).

Further *t*-tests confirmed that the two types of cognates (Dutch–English vs. French–English) were not significantly different in terms of word length, English word frequency, concreteness, or orthographic Levenshtein distance (all  $ps > .13$ ). English neighbourhood density (CLEARPOND; Marian et al., 2012) was higher for the Dutch– than French–English cognates ( $p = .009$ ), whereas OLD20 was higher for French–English cognates ( $p = .005$ ). The Dutch–English and French–English control words did not differ significantly on any of these measures (all  $ps > .053$ ). Finally, there were no significant differences across Dutch (Keuleers et al., 2010) ( $p = .602$ ) or French (New et al., 2004) ( $p = .876$ ) word frequencies for each cognate type, but within each cognate translation pair (e.g., *knoflook/ail*), word frequency was significantly higher in French than in Dutch ( $p < .001$ ).

An additional 144 words were chosen as filler items, of which 45 were non-cognates in all three languages, 33 were French–Dutch cognates, and 66 were cognates among all three languages. Thus, 59% of all stimuli (targets and fillers) consisted of cognates. The stimulus list included 288 non-words following English orthotactics, which were

**Table 4.3.** Lexical characteristics of target words by cognate language and word type.

	Cognate language			
	Dutch–English		French–English	
	Cognate	Control	Cognate	Control
Frequency (English)	4.55 (0.51)	4.51 (0.42)	4.47 (0.50)	4.40 (0.52)
Frequency (Dutch)	4.25 (0.62)	4.37 (0.56)	4.16 (0.71)	4.32 (0.57)
Frequency (French)	4.45 (0.59)	4.59 (0.55)	4.47 (0.41)	4.42 (0.60)
Concreteness	4.48 (0.66)	4.44 (0.76)	4.35 (0.71)	4.41 (0.73)
Word length	5.00 (0.90)	4.90 (0.90)	5.30 (1.00)	5.40 (1.00)
OLD20	1.66 (0.31)	1.70 (0.32)	1.90 (0.40)	1.74 (0.41)
English neighbourhood size	7.30 (5.90)	6.00 (4.20)	4.10 (4.00)	6.10 (5.40)
Dutch neighbourhood size	3.90 (4.00)	1.70 (2.60)	1.80 (3.10)	1.70 (3.00)
French neighbourhood size	0.80 (1.30)	1.70 (2.00)	2.90 (2.90)	1.10 (2.10)
Orth. dist. Dutch–English	.79 (.14)	.10 (.11)	.09 (.11)	.11 (.12)
Orth. dist. French–English	.14 (.14)	.16 (.13)	.80 (.15)	.15 (.13)
Orth. dist. Dutch–French	.12 (.14)	.09 (.10)	.08 (.11)	.14 (.11)

*Note.* Standard deviations in parentheses. Orth. dist. = Orthographic distance.

generated using the Wuggy software (Keuleers & Brysbaert, 2010). The words given to Wuggy were chosen pseudo-randomly from the SUBTLEX-UK database and each non-word was matched in length with an experimental or filler item. All non-words were checked by a native speaker of Dutch and French to ensure that they were not real words in the two languages.

### 4.2.3 Design and Procedure

The experiment consisted of a  $2 \times 2 \times 2$  design with a within-participants between-items factor of cognate status (cognate vs. non-cognate), a within-participants between-items factor of cognate language (Dutch–English vs. French–English), and a between-participants within-items factor of language of instruction (Dutch vs. French).

The experiment was administered through a web browser in jsPsych (Version 6.3.1; de Leeuw, 2015). After obtaining informed consent, participants completed the lexical decision task. Written instructions were presented in English before the task. All 576

words were presented on the screen in Courier New font (size 48) one word at a time, with the order of the items individually randomised per participant. Participants were instructed to indicate by means of a button press whether the word presented on the screen was a real English word (right finger) or not (left finger) as quickly and accurately as possible. The task was preceded by 10 practice trials. A fixation cross was presented on the screen for 500 ms at the start of each trial, with a blank screen shown for 50 ms between the fixation cross and the stimulus. Each word remained on the screen for 2000 ms or until the participant made a response, followed by a blank screen for 500 ms before the next trial started.

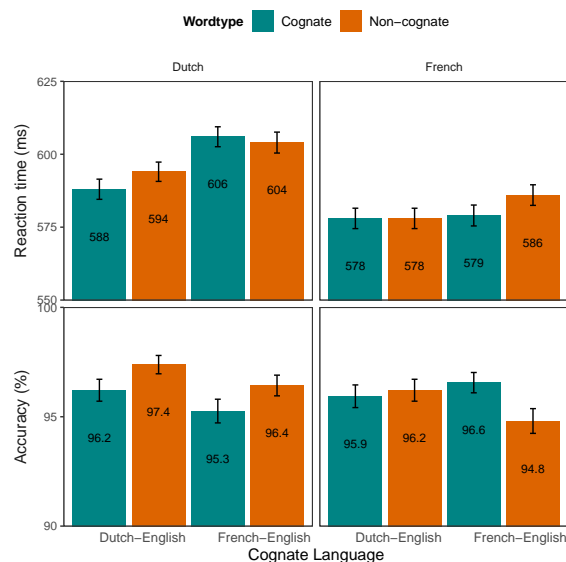
Participants were asked to take two breaks for as long as they wanted during the experiment, with the stimuli presented in three blocks of 192 words. After the lexical decision task, participants were asked to fill out demographic information as well as a language history questionnaire with self-reported proficiency in English, Dutch, and French. The questions for the language history questionnaire were adapted from LEAP-Q (Marian et al., 2007). Finally, participants completed the English LexTALE (Lemhöfer & Broersma, 2012) as well as the Dutch (Lemhöfer & Broersma, 2012) or French (Brysbaert, 2013) version of the LexTALE, for the Dutch-LOI and French-LOI groups, respectively.

## 4.3 Results

Four items with accuracy below 2.5 standard deviations from the mean item accuracy ( $M = 95.5\%$ ,  $SD = 5\%$ ) of the experimental items were excluded (the Dutch–English cognates *spear*: 81.8% and *liver*: 81.8%, the Dutch–English non-cognate *bribe*: 68.2%, and the French–English cognate *vein*: 73.9%). We also removed their matched control words, removing in total eight items. We used linear mixed-effects models (*lme4*-package in *R*; Bates et al., 2015) to analyse RTs and accuracy on the lexical decision task on cognate and non-cognate words. A  $t/z$ -value of  $| 1.96 |$  was set as the threshold for significance, corresponding to a  $p$ -value of .05.

### 4.3.1 Reaction Time Analysis

RTs are plotted in the upper panel of Figure 4.2. We analysed only correct trials (96.1% of the data). Trials below 300 ms and trials with RTs more than 2.5 SDs from each participant's mean were excluded (3.4% of the remaining data). Following Barr (2013),



**Figure 4.2.** Upper panel: Mean lexical decision times for cognates and controls by cognate language and group (left panel: Dutch-LOI; right panel French-LOI), Lower panel: Mean lexical decision accuracy for cognates and controls by cognate language and group (left panel: Dutch-LOI; right panel French-LOI). Error bars represent the standard error of the mean.

a maximal random effects structure justified by the design that would converge was included in the model. The final regression model included cognate status (cognate vs. non-cognate, sum-coded) and congruency (i.e., whether the cognate language (Dutch-English vs. French-English) was congruent with the participant's language of instruction (Dutch or French) or not, sum-coded), as well as their interaction as fixed effects,<sup>6</sup> random intercepts for participants and items, as well as random slopes for congruency by participants. The outcome variable was inverse transformed ( $-1000/RT$ ).<sup>7</sup>

The model output is shown in Table 4.4. Likelihood-ratio tests revealed that the two-way interaction between cognate status and congruency was significant ( $\chi^2(1) = 8.52$ ,  $p = .004$ ) when the model was compared to a model including only the main effects. To ensure the interaction was not driven by differences in Dutch and French word frequency,

<sup>6</sup>To ensure that the results were not influenced by differences in L1 neighbourhood density between cognates and controls, or by English neighbourhood density and OLD20 between the two cognate types (see Section 4.2.2), initial analyses included these variables as control variables. However, none of these variables were significant predictors of RTs, nor did they improve model fit or alter the significance of the variables reported here.

<sup>7</sup>We compared models with no transformation, log transformation, and inverse transformation of the outcome variable. The latter transformation provided the best model fit as determined by visual inspection of the plots using the function *check\_model* from the package *performance* (Lüdtke et al., 2021) in R.

**Table 4.4.** Model output for the RT and accuracy regression analyses.

	RT			Accuracy		
	Estimate	SE	t-value	Estimate	SE	z-value
Intercept	−1.77	0.02	−86.31	3.88	0.14	27.32
Cognate status	−0.01	0.02	−0.52	0.08	0.20	0.43
Congruency	−0.01	0.01	−2.06	0.07	0.14	0.59
Cog. status*Congruency	−0.03	0.01	−2.92	0.24	0.20	1.20

*Note.* SE represents the standard error of the co-efficient.

these variables were included as covariates. Including these variables improved model fit ( $\chi^2(2) = 30.16, p < .001$ ), but the interaction remained significant, indicating that it is not driven by differences in lexical frequency. Comparing a model with only cognate status as a predictor to a null model showed that there was no main effect of cognate status ( $\chi^2(1) = 0.28, p = .599$ ).

Post-hoc pairwise comparisons using the *emmeans*-package (Lenth, 2025) in *R* revealed that the interaction was driven by the differences in RTs between Dutch–English and French–English cognates in the group with Dutch-LOI (estimated difference = 18 ms,  $SE = 8, p = .028$ ), meaning that Dutch–English cognates had on average faster RTs than French–English cognates. For the French-LOI group, there were no significant differences between French–English or Dutch–English cognates (estimated difference = 2 ms,  $SE = 8, p = .847$ ).<sup>8</sup> In both groups, there were no significant differences between cognates and non-cognates for any cognate language (all  $ps > .288$ ). Lastly, there was a significant difference in RTs between the Dutch-LOI and French-LOI groups for French–English cognates (estimated difference = 28 ms,  $SE = 14, p < .049$ ), with shorter RTs for the group with French-LOI than the group with Dutch-LOI.

For one of the groups, the Dutch-LOI, the RTs for cognates between the target language and the language of instruction were shorter than those of cognates between the target language and another known language. Although we did not observe a classic cognate effect, where the facilitation in processing is observed in RTs between cognates and non-cognates, our results are compatible with the hypothesis that a cognate effect only occurs for cognates between two languages used during learning: for cognates

<sup>8</sup>The test was performed and is reported here with raw RTs as the outcome variable, for interpretability of the results. Similar results were obtained when the test was performed on inverse-transformed RTs.

between the target language and the participants' other known language, there were either no differences or a numerical inhibition effect. To further shed light on this hypothesis, we ran an analysis on a subset of our data, where only Dutch–English cognates and their controls were included for the Dutch-LOI group and only French–English cognates and controls for the French-LOI group, to test whether a cognate effect only occurs for cognates between the target language and the language of instruction. Cognate status on its own was not a significant predictor of RTs ( $b = -0.02$ ,  $SE = 0.02$ ,  $t = -1.52$ ), nor did it interact with group ( $b = -0.01$ ,  $SE = 0.03$ ,  $t = -0.34$ ). A separate analysis revealed that there was also no interaction between cognate status and L3 English proficiency, as measured by the LexTALE ( $b = 0.001$ ,  $SE = 0.001$ ,  $t = -0.86$ ).<sup>9</sup>

### 4.3.2 Accuracy Analysis

Accuracies are plotted in the lower panel of Figure 4.2. The maximal model that would converge for the accuracy analysis when the optimiser *bobyqa* was used, included cognate status and congruency, as well as their interaction, as fixed effects, random intercepts for participants and items, and random slopes for cognate status and congruency by participants. The interaction between cognate status and congruency was not significant ( $\chi^2(1) = 2.31$ ,  $p = .128$ ).<sup>10</sup>

When only cognates and controls between the target language and the participants' language of instruction were analysed, cognate status on its own was not significant ( $b = 0.18$ ,  $SE = 0.28$ ,  $z = 0.65$ ), and a separate analysis revealed that there was no significant interaction between cognate status and L3 English proficiency ( $b = 0.02$ ,  $SE = 0.01$ ,  $z = 1.7$ ). However, when the data from the groups were analysed separately, this revealed a significant interaction between cognate status and L3 proficiency in the Dutch-LOI group ( $b = 0.05$ ,  $SE = 0.02$ ,  $z = 2.71$ ), but not in the French-LOI group ( $b = -0.01$ ,  $SE = 0.02$ ,  $z = -0.36$ ). This suggests that for the Dutch-LOI group, higher proficiency in the target language leads to better accuracy for cognates compared to non-cognates.

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<sup>9</sup>Similar results were obtained when the model included Levenshtein distance as a measure of cognate status, to confirm that there was not a graded cognate effect as in e.g., Duyck et al. (2007).

<sup>10</sup>This model comparison was performed without estimating the correlation for the random effects as the reduced model produced a singular fit error otherwise.

## 4.4 Discussion

In this study, we investigated whether the cognate effect was influenced by the language of instruction to determine if the effect only occurs for cognates between an L3 and its language of instruction, compared to cognates between the L3 and an L2, which was not used during learning. To do this, we measured RTs and error rates in an L3 English LDT among two groups of Dutch–French–English trilinguals. One group had learned L3 English through their L1 Dutch and the other group had learned it through L1 French. Participants saw either Dutch–English cognates (overlapping in form with their translation equivalent in the language of instruction for the Dutch-LOI group) or French–English cognates (overlapping in form with their translations in the language of instruction for the French-LOI group) as well as matched non-cognate control words. If the acquisition of cognates in an L3 (i.e., the target language of the LDT) involves co-activation of lexical representations with the language of instruction, and not with another known language not used during learning, we expect cognate effects to be modulated by the language of instruction, by observing cognate effects for Dutch–English cognates and not French–English cognates for the Dutch-LOI group, and the opposite pattern for the French-LOI group. If, however, cognate learning leads to co-activation between existing lexical representations in any language, we would expect to see cognate effects for both types of cognates.

We found differences in lexical decisions only for cognates between the target language and the language of instruction, but these effects emerged mainly for the Dutch-LOI group. Dutch–English cognates were recognised faster (18 ms) than French–English cognates for the Dutch-LOI group, and French–English cognates were recognised faster (28 ms) by the French-LOI group than the Dutch-LOI group. Additionally, participants in the Dutch-LOI group who were more proficient in the target language were more accurate on Dutch–English cognates compared to non-cognates. These findings are convergent with those of Szubko-Sitarek (2015), who found a cognate effect for L1–L3 cognates, but no effects between L2–L3 cognates for participants who had acquired the L3 through their L1. Our results are more in line with our hypothesis, based on Costa et al. (2017), which assumes that co-activation only occurs between form-similar lexical representations in an L3 and its language of instruction, than an account, such as the scaffolding model (Bartolotti & Marian, 2017), where co-activation occurs across form-similar lexical representations of any existing languages. Nevertheless, the findings could be compatible with the latter account where the L1 plays a

larger role than any other known languages in utilising form similarities to facilitate learning.

Two results from our study were surprising: first, the absence of significant differences between cognates with the language of instruction and their matched non-cognates, and second, the differences in cognate effects that were observed in the two groups. As discussed by Hirosh and Degani (2018), both learners and the languages involved in learning contribute a multitude of factors, such as age of acquisition and proficiency, learning circumstances, as well as similarities between languages, which may affect how resources are utilised during the acquisition of a novel language. Below, we discuss each of these factors and how they may have contributed to our results, address limitations of our study, and provide suggestions for future research.

The absence of any significant differences between cognates with the language of instruction and the non-cognates could be attributed to the high proficiency in the target language (L3 English) among our participants. Previous studies have shown smaller cognate effects with increased L2 (i.e., target language for the cited studies) proficiency in bilinguals (Libben & Titone, 2009; Pivneva et al., 2014; Schwartz & Kroll, 2006). Cognate facilitation in L3 processing has been found to be modulated by L3 proficiency in that on the one hand, a certain degree of proficiency is necessary for the effect to manifest (Zhu & Mok, 2020), but on the other, and similarly to bilinguals, if proficiency is high, the effect is reduced (Poarch & van Hell, 2014). It is possible that our sample was too proficient in the target language to exhibit any large cognate effects, however, we still observed an interaction with the language of instruction.

Another way in which proficiency could have affected our results is the proficiency in the L2. The L2 proficiency of our participants may seem low, especially compared to their L3 proficiency. One might query whether a cognate effect would emerge for cognates between the target language and the L2 if the L2 proficiency of our sample was higher. For instance, as per Costa et al. (2017), higher proficiency could modulate the degree of cross-talk during learning, but it is unclear whether this applies only if the language is actively used during learning. Furthermore, previous research suggests that proficiency in the L1 and L2 may affect the degree of influence from the L1 vs. the L2 on the L3 (Lindqvist, 2010). However, our groups were matched on self-rated L2 proficiency, and only participants who reported being fluent in the L2 and who scored above a certain threshold on the L2 vocabulary tests were included in the study. Additionally, if higher L2 proficiency affects the degree of co-activation and influence from the L2 to the L3, we would expect to observe cognate effects for L2–L3 cognates in

the French-LOI group, as they had a higher L2 proficiency compared to the Dutch-LOI group. However, no cognate effects were observed for these cognates for this group, suggesting that L2 proficiency does not explain our results.

The lack of any significant effects for cognates with the language of instruction for the French-LOI group could be explained by the global linguistic distance between the language pairs, as English is more typologically similar to Dutch (both West-Germanic languages) than French (Romance language) (Hammarström et al., 2024). Previous research has shown that in both L2 and L3 learning, learnability, i.e., the extent to which existing languages aids or impedes the learning of a new language, of a new language decreases as linguistic distance to the existing languages increases (Schepens, Van Der Slik, & Van Hout, 2013a, 2013b; Schepens et al., 2016). In L3 learning, the relative influence of the L1 vs. the L2 may depend on which language more closely resembles the L3 (e.g., Ahukanna et al., 1981; Schepens et al., 2016). In a large-scale study with over 39,000 participants, Schepens et al. (2016) demonstrated that approximately half of the variation in speaking proficiency scores in L3 Dutch was explained by lexical and morphological distances between participants' L1 and the L3, and about 30% of the variance was explained by distance between the L2 and the L3.

If our results were driven by the typological similarities between the L3 and the language of instruction, we would expect smaller differences between non-cognates and cognates with the language of instruction in the French-LOI group than in the Dutch-LOI group. Looking at the raw RTs and error rates, the French-LOI group displayed larger numerical differences between these cognates and non-cognates compared to the Dutch-LOI group, which do not fit with the patterns expected if the group differences were explained by the global linguistic similarities between the language pairs.

Different learning circumstances could also have influenced the slightly different results between our groups. Our participants were engaged in classroom-based L3 learning, with some variation in how they acquired their L2 (12 reported not being raised monolingual). It is worth questioning whether the account by Costa and colleagues extends to different learning environments, such as lifelong or immersion-based language acquisition. Making general predictions for these groups is challenging because their circumstances, including the degree of exposure to each language, vary significantly from formal language education. Classroom-based L3 word learning is often mediated through translation equivalents, which may not be the case for non-classroom learners, which makes the role of a language of instruction becomes less important in informal learning scenarios. Whether or not the presence of translation equivalents is necessary

for cognate learning advantages to emerge is a question left open for future research.

In addition, learners within the same learning scenario may have been subjected to different learning methods and strategies, which may further influence how cognates are learned. For instance, cognate awareness might be emphasized differently by different instructors in classroom-based settings. Awareness of cross-linguistic similarity has been assumed to benefit cognate learning in classroom settings (e.g., Otwinowska-Kasztelanic, 2011), which may not only affect their learning and processing, but a learner's prior experience with such strategies can also influence vocabulary learning in subsequently acquired languages. However, for our study, the potential differences in learning strategies between our participants is unlikely to have affected our results, as there is evidence that cognate awareness may not be so influential. For instance, Otwinowska et al. (2020) found no differences in tasks such as reading and identifying cognates in text between participants who were trained on cognate awareness and participants who were not specifically trained on these vocabulary learning strategies, suggesting that awareness of cross-linguistic similarity is not required for the cognate advantage.

One limitation of our study is the overlapping roles of the language of instruction and the L1, which makes it challenging to isolate the effects of language dominance during both learning and processing. Firstly, a crucial question is whether our findings would hold if the L3 was learned through the L2. The findings of Hirosh and Degani (2021), who found an advantage for learning non-cognate but not cognate words through the L1 relative to the L2, suggest that they would. However, further studies suggest that cognate learning and processing may be affected by the status of the language of instruction. For instance, Bogulski et al. (2019) examined the learning of L3 Dutch words through L1 or L2 English among English–Spanish, Spanish–English, and Chinese–English bilinguals, as well as English monolinguals. Only English–Spanish bilinguals had an accuracy advantage in word learning, which the authors attribute to the benefit of having the L1 as the language of instruction.

A second crucial question is whether the effects we observed are driven by the dominance of the L1, potentially making cognate effects more likely. However, previous research suggests otherwise: cognate effects seem to be stronger in the less dominant language (in both children and adults: Costa et al., 2000; Méndez Pérez et al., 2010; Robinson Anthony and Blumenfeld, 2019; Robinson Anthony et al., 2020; Rosselli et al., 2014, though see Carrasco-Ortiz et al., 2021). If our results were driven by language dominance, we would expect cognate effects between the target language and

the non-dominant language, i.e., the language not used during learning, which is not what we observed. Nevertheless, future work should address how language dominance and cognate effects interact with learning.

In relation to our study, it is unclear whether the results of Bogulski et al. (2019) are applicable to cognate learning. Although a quarter of their stimuli were Dutch–English cognates, the effect of cognateness was not taken into account. A prediction based on the account by Costa et al. (2017) is that both learning and processing advantages should be observed for cognates between any languages involved in learning. However, it may be that there is reduced cross-talk between L2–L3 cognates during learning due to weaker L2 lexical representations and links (see e.g., the weaker links hypothesis: Gollan et al., 2008) relative to those of L1 representations. This may result in “less enhanced” representations and a smaller cognate advantage for the newly learned L3 cognates if the L2 is the language of instruction. Future studies should therefore investigate how cognateness, the language of instruction, and the native language interact, and current models of vocabulary acquisition should address the mechanisms that could lead to the benefit for L1 transfer in word learning.

Lastly, our remote testing procedure may have introduced inaccurate measurements due to varying system and equipment setups among participants. According to Bridges et al. (2020), the inter-trial variability of jsPsych across different browsers and operating systems ranges from 5–10 ms. While this may seem negligible, cognate effects are small, and perhaps require more precise measures (e.g., the cognate facilitation effect in Poort and Rodd (2017), who collected data remotely using the Qualtrics Reaction Time Engine, was about 31 ms for identical cognates).

#### **4.4.1 Conclusion**

To conclude, the present study provides evidence that L3 cognate recognition is affected by the language of instruction, suggesting that co-activation during L3 learning may be restricted to representations in the language of instruction. Understanding how the language of instruction influences cognate processing in trilingual contexts can provide crucial insights into the mechanisms underlying language learning and bilingual language processing. This knowledge can inform our current models of multilingual word learning and processing, and further also language education practices, contributing to the development of effective language learning strategies.

## Chapter 5

# Do Bilinguals Predict Cognates More Than Non-Cognates in Their Non-Native Language?

Bilinguals predict upcoming information when they are using their non-native language (L2), but it is less clear whether they predict phonological form, or whether they predict in their native language (L1) when using their L2 (Ito et al., 2018). In this study, we address these questions by asking whether overlapping information between L1 and L2 form representations affects L2 prediction and whether prediction on the phonological level is language selective, involving (pre-)activation of representations in only the target language, or also in the non-target language. Using a visual world paradigm, we investigated the extent to which the cognate status of a word affects its prediction in L2 comprehension. Cognates are translation equivalents that share phonological and/or orthographic form and meaning across languages (e.g., *pipe* and *pijp* in English and Dutch), and their processing is usually facilitated compared to non-cognates. We tested whether bilinguals are more likely to predict cognates than non-cognates. If prediction of form is language non-selective, bilinguals should be more likely to predict cognates than non-cognates. Our results show that participants did predict the meaning of upcoming words but that the cognate status of the referent does not affect its predictability. These findings provide further evidence that bilinguals predict upcoming words in an L2, but that the prediction of phonological form may be language selective and is not aided by overlapping information between the L1 and the L2.

## Foreword

Building on the previous chapters, which have explored the mechanisms underlying bi- and multilingual word recognition and sentence processing with a focus on learning-based theories, this chapter shifts the focus to predictive processing in a non-native language. While Chapter 4 provided empirical evidence supporting the role of learning-based mechanisms in multilingual word recognition, this chapter investigates non-selectivity in L2 prediction. Specifically, it addresses whether bilinguals predict phonological form in their non-native language in a non-selective manner. The results of this chapter provide further insights into non-selective activation in bilingual word recognition by investigating whether corresponding L1 representations of upcoming L2 input are activated non-selectively *before* the input is processed. These findings contribute to the broader discussion in this thesis by exploring how prediction interacts with language selectivity, an important aspect of processing mechanisms discussed in earlier chapters, particularly in relation to non-selective activation (Chapter 1 and Chapter 2).

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## 5.1 Introduction

Bilinguals are able to predict upcoming information when they are using their non-native language (L2). For instance, they use verb semantics to predict what word might come next in a sentence (e.g., Dijkgraaf et al., 2017). Predictive processing in language is thought to involve the pre-activation of linguistic representations of words before the actual words are processed as input (e.g., Pickering & Gambi, 2018). However, given that bilinguals operate with two languages instead of one, as is the case with monolinguals, the question arises: what effect, if any, does native language (L1) knowledge have on predictive processing in an L2? Kaan (2014) and Kaan and Grüter (2021) suggest that factors such as language competition, exposure, and the quality of lexical representations can lead to different patterns of prediction in bilinguals compared to monolinguals. Recent studies indicate that non-native speakers exhibit

similar patterns as native speakers in the prediction of semantics, but that the activation of semantic information during L2 prediction is delayed (Dijkgraaf et al., 2017; Ito et al., 2018) and less robust (Dijkgraaf et al., 2019). Furthermore, findings from several other studies indicate that L2 speakers are less likely than L1 speakers to predict lexical and syntactic information, such as phonological features (Ito et al., 2018; C. D. Martin et al., 2013) or grammatical gender (Hopp & Lemmerth, 2018; though see Foucart et al., 2014, 2016).

When it comes to predicting semantics, such as upcoming referents, bilinguals seem to behave similarly to monolinguals, but there is some evidence that semantic prediction in an L2 is slower compared to in an L1. For instance, in a visual-world experiment, Dijkgraaf et al. (2017) found that both Dutch–English bilingual and English monolingual participants, when listening to English sentences with constraining sentence contexts (such as *Mary reads a ...*), showed a higher proportion of looks toward target objects (e.g., a letter) than toward unrelated objects (e.g., a car) between the onsets of the verb and target word. The effect was not significantly different between bilinguals and monolinguals. However, an analysis of the time course revealed a slight delay (approximately 100 ms) in the predictive eye movements of the bilingual participants.

In a similar study, Dijkgraaf et al. (2019) tested Dutch–English bilinguals listening to sentences (e.g., *Her baby doesn't like drinking from a bottle.*) in L1 and L2 and found more looks toward both target (e.g., a bottle) and semantic competitor objects (e.g., a glass) relative to unrelated distractor objects. In line with their earlier results, the effect was slower in the L2 than L1. Additionally, the proportion of looks was higher (compared to unrelated objects) for competitors that were more related to the target, an effect that was stronger in the L1 than in the L2. Taken together, these results suggest that while bilinguals can predict upcoming meaning in their L2, non-native semantic prediction may be delayed and less robust.

Dijkgraaf et al.'s (2017) explanation for delayed predictive processing in the L2 is based on the weaker links hypothesis (Gollan & Kroll, 2001; Gollan et al., 2008), which posits that the links between L2 lexical representations (e.g., semantics and form) and their use in context are less accurate than in an L1 due to a reduced exposure to the L2. This may lead to retrieval difficulties during processing, which may in turn affect the generation of predictions, making them 'slower, less accurate or weaker' (Dijkgraaf et al., 2017, p. 918). They further discuss this account in Dijkgraaf et al. (2019), arguing that the lower subjective word frequency of L2 words (compared to L1 words) results in a delayed activation of word form, and subsequently a slower spread of semantic

activation.

While L2 speakers appear to predict semantic information similarly to L1 speakers, there is no evidence that they predict the phonological form of upcoming input in their L2. For example, in another visual world study, Ito et al. (2018) also found that the time-course of prediction in an L2 was delayed compared to L1 prediction: Japanese–English bilinguals were slower than native English speakers at looking at a predictable target object (e.g., a cloud – *kumo* in Japanese) before hearing the target word in sentences like *The tourists expected rain when the sun went behind the cloud*. Moreover, L1 speakers looked predictively at English phonological competitor objects (e.g., a clown), suggesting that these participants also predicted phonological features of the upcoming input. However, the bilingual participants did not look predictively at the L2 English competitors or L1 Japanese competitor objects that were phonologically related to the target word in Japanese (e.g., a bear – *kuma* in Japanese), leading the authors to conclude that the prediction of phonological information occurs in L1 comprehension but not in L2 comprehension.

Ito et al. (2018) proposed that their findings might be explained by the prediction-by-production account (Pickering & Garrod, 2007, 2013). According to this account, the mechanisms involved in language production are used to predict the next part of an utterance: when predicting words, listeners pre-activate the relevant representations (such as meaning and sound) of a predictable word as if they were producing it. However, fully engaging the production system requires time and cognitive resources, making phonological predictions less likely when resources are limited. The authors therefore hypothesised that the difficulties associated with L2 production (e.g., with post-lexical processes (Broos et al., 2018)) make it less likely that phonological representations will be formed, than they will in L1 production.

Ito et al. (2018) also discussed the possibility that L2 speakers may predict in both their languages simultaneously, making L2 prediction more effortful than L1 prediction. This proposal is based on the assumption that bilinguals co-activate lexical representations across languages in a non-selective manner, meaning that L1 translation equivalents and their phonology may be activated during on-line lexical access (e.g., Dijkstra & van Heuven, 2002; Dijkstra et al., 2019; Spivey & Marian, 1999). As a result, activation of representations in the L1 could cause interference, leading to delayed access to L2 lexical representations during prediction (Foucart, 2021; Ito & Pickering, 2021; Ito et al., 2018, 2024). For example, Ito et al. (2024) discuss the possibility that bilinguals may base their predictions on L1 representations and not L2 representations.

Conversely, when there is overlapping information between L1 and L2 representations, predictive processing in an L2 might become less effortful because congruency between co-activated representations could facilitate the generation of predictions (Foucart, 2021; Foucart et al., 2016; Ito et al., 2024). For instance, Hopp and Lemmerth (2018) found that native German intermediate learners of Russian showed native-like patterns of syntactic predictions of gender features only when the gender marking was syntactically congruent with participants' L1.

The explanations outlined above for reduced L2 prediction suggest that predictive processing in the L2 may be weakened due to limited language exposure, challenges associated with L2 production, or competition from the L1. However, a common thread is that overlapping information between L1 and L2 lexical representations might make predictive processing less effortful.

Cognates — translation equivalents that are orthographically and/or phonologically similar across languages — provide an interesting case for investigating predictive processing in an L2 because information overlaps both on the form and semantic levels. Cognates (e.g., *cat* – *kat* in Dutch) typically lead to facilitated processing in bilinguals, with faster processing times compared to non-cognate control words (e.g., *dog* – *hond* in Dutch). These findings hold for L2 processing across domains and modalities, such as comprehension in isolation (written word recognition: e.g., Dijkstra et al., 1999; Tiffin-Richards, 2024; spoken word recognition: Fricke, 2022, though cf. Cornut et al., 2022; Guediche et al., 2023), and also in production (e.g., Costa et al., 2000; Hoshino & Kroll, 2008; Muylle et al., 2022; Starreveld et al., 2014). Importantly, cognate processing has been found to be facilitated when they occur in sentence contexts (e.g., Duyck et al., 2007; Libben & Titone, 2009).<sup>1</sup>

The cognate facilitation effect is usually explained by the assumption that the simultaneous activation of lexical representations in the L2 and the L1 provide a higher level of activation on the form level for cognates as the activation stems from two sources rather than one, as is the case for non-cognates. This non-selective activation results in faster activation of semantic representations for cognates relative to non-cognates in comprehension (Dijkstra & van Heuven, 2002; Dijkstra et al., 2019), or in production, faster activation and selection of the form representations of cognates relative to those of non-cognates (Costa et al., 2000).

Ito et al. (2024) investigated whether cognates affect prediction in a visual world

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<sup>1</sup>Although high semantic constraint may reduce or eliminate the effects, a meta-review showed that the pooled effect size for cognate facilitation remains significant (Lauro & Schwartz, 2017).

experiment. Spanish–English and Chinese–English bilinguals listened to predictable or unpredictable sentences where the verb was either a cognate (e.g., *adopt* – *adoptar*) or a non-cognate (*bake* – *hornear*) between Spanish and English (but not between Chinese and English). In the visual display, only one of the four objects (e.g., a dog) was an appropriate referent of the verb in the predictable condition, whereas all four objects (e.g., a dog, a cat, a rabbit, a hamster) were appropriate referents of the verb in the unpredictable condition. Confirming previous findings, both groups looked predictively at the target in the predictable vs. unpredictable condition. Furthermore, the interaction between cognate status, predictability and L2 proficiency was significant only in the Spanish–English group, with lower proficiency participants showing larger predictability effects in the cognate than the non-cognate condition, and higher proficiency participants showing smaller predictability effects in the non-cognate than the cognate condition. A divergence point analysis revealed that the participants with low proficiency predicted the target earlier when the verb was a cognate than when it was not.

Ito et al. suggest that cognate verbs were either more strongly activated than non-cognate verbs, allowing for more efficient use of verb semantics for prediction, or more quickly activated, freeing up time or cognitive resources for predictive processing. They conclude that their findings are compatible with proficiency-dependent models, such as the BIA-d model (Grainger et al., 2010), RHM (Kroll & Stewart, 1994), and MULTILINK model (Dijkstra et al., 2019). In relation to non-selective activation, they hypothesise that the results suggest that more proficient L2 speakers may rely less on L1 representations during L2 processing, or that they co-activate L2 verb meanings that are not in the L1 translation equivalent (e.g., *move* can refer to changing residence in English, but its Spanish cognate *mover* does not), thereby reducing the facilitation from form overlap.

The current study investigates whether L2 speakers also show a cognate advantage in predictive processing when the predictable target is a cognate, and whether shared form-level information aids prediction in the L2. Specifically, we ask whether the prediction of cognates occurs earlier and is stronger than that of non-cognates. According to the accounts discussed above, the prediction of cognates should facilitate, rather than hinder, L2 prediction. For example, Dijkgraaf et al.'s (2017, 2019) account suggests that reduced L2 exposure results in lower subjective word frequency for L2 words, leading to slower activation of form and semantics during prediction. However, within this theoretical framework, cognates could be argued to have a higher subjective word frequency compared to non-cognates due to their cumulative frequency across the

L1 and L2 (Midgley et al., 2011; Strijkers et al., 2010), or alternatively, it could be that cognates are learned better due to their form overlap, leading them to have more prominent representations relative to non-cognates (Costa et al., 2017). This qualitative difference between the lexical representations of cognates and non-cognates could mitigate the delay in activation if the predicted word is a cognate.

Similarly, if L1 activation affects predictive processing, as suggested by Foucart (2021) and Ito et al. (2018, 2024), the prediction of cognates should be facilitated relative to non-cognates, as the co-activation of L1 representations may aid their processing, consistent with explanations of cognate facilitation that assume on-line simultaneous activation (e.g., Costa et al., 2000; Dijkstra & van Heuven, 2002).

A cognate advantage is also expected under the prediction-by-production account discussed by Ito et al. (2018), as cognates are easier for L2 speakers to produce (Costa et al., 1999, 2000). Thus, if L2 prediction engages the production system, the cognate status of the upcoming input should facilitate the process.

However, it is also possible that during prediction, L1 representations, and particularly phonological representations, are not (pre-)activated due to cognitive constraints, such as limited cognitive resources. If this is the case, no cognate advantage would be expected; nevertheless, these findings would still be consistent with Ito et al. (2018).

### 5.1.1 The Current Study

Using a visual world paradigm, we tested whether bilinguals have a processing advantage for cognates in L2 prediction, specifically examining whether cognate words are more likely to be anticipated as upcoming input than non-cognate words. This paradigm has been extensively used to investigate predictive processing as it offers insights into the time-course of on-line prediction. For instance, an early study by Altmann and Kamide (1999) demonstrated that listeners anticipate specific words based on sentence context, such as fixating more often on an image of a kite rather than an airplane before hearing the target word in sentences like *The boy went out to the park to fly a kite*.

We examine whether the cognate status affects the time-course and the likelihood of predictive looks to target objects that are compatible with the sentence context. In our experiment, Dutch–English bilinguals viewed four objects on a screen whilst listening to sentences such as *The man wanted to buy a new pipe*. Two of the objects in the display (e.g., a pipe and a wallet) were appropriate referents of the verb (e.g., *buy*), while the other two (e.g., a priest and a plumber) were unrelated objects that were not

compatible with the verb. We manipulated the cognate status of the names of the target objects, such that one was a cognate with its Dutch translation (e.g., *pipe* – *pijp* in Dutch) and the other a non-cognate (e.g., *wallet* – *portemonnee* in Dutch). We measured the proportion of looks to the objects between the verb onset and the onset of the target word to determine whether (1) bilinguals predict upcoming referents, and (2) cognates received earlier and more predictive looks than non-cognates to test whether cognate status can aid predictive processing in L2 listening.

If language co-activation or reduced language exposure affects L2 prediction, we expect target objects in the visual world array with cognate names to elicit earlier and a higher proportion of predictive eye movements compared to non-cognate target objects. If our results support this prediction, it would suggest that bilinguals can predict phonological form, and that they activate the phonological forms of both languages when predicting upcoming words in their L2. Furthermore, it would imply that the prediction of phonological features may be non-selective with regard to language, rather than being restricted to the pre-activation of phonological representations in only the target language.

Given that cognate effects are known to interact with language proficiency in that the effect is reduced with increased proficiency (in sentence context: Libben and Titone, 2009; in production: Starreveld et al., 2014; in listening: Fricke, 2022), we conducted an exploratory analysis where we examined whether the difference in predictive looks to cognates and non-cognates was modulated by L2 proficiency. Additionally, as previous research has demonstrated that cognate effects in written sentence comprehension are graded, with a continuous measure of cognate status being a better predictor of reading times than a binary measure (Duyck et al., 2007), we conducted another exploratory analysis to investigate whether the degree of phonological overlap would modulate the cognate effect in L2 prediction.

## 5.2 Methods

### 5.2.1 Participants

40 native Dutch (Belgium or Netherlands) speakers fluent in English (between 18–28 years;  $M_{age} = 21.1$  years,  $SD_{age} = 2.6$ ; 30 female, 9 male, 1 other) were recruited through the SONA system at Ghent University. Participants had corrected or normal-to-corrected vision, no known language impairments and were paid €5 for participation.

**Table 5.1.** Descriptive statistics of participants' language experience and proficiency.

	<i>M</i>	<i>SD</i>
Age of L2 acquisition (years)	10.5	3.0
L2 usage (%)	24.1	20.7
L1 usage (%)	75.2	17.6
Reading <sup>a</sup>	8.1	1.0
Speaking <sup>a</sup>	7.2	0.8
Comprehension <sup>a</sup>	8.2	0.9
LexTALE score	81.8	9.5

*Note.* *M* and *SD* represent mean and standard deviation, respectively.

<sup>a</sup>Self-rated level of proficiency in L2 English on a 10-point Likert scale (0 = None; 10 = Perfect).

Data from one participant was excluded due to an issue with the keyboard, and a new participant was tested in their stead. Descriptive statistics for the participants' language experience and proficiency scores are laid out in Table 5.1.

### 5.2.2 Materials

We used the method described in Schepens, Dijkstra, et al. (2013) to compute phonological Levenshtein distance<sup>2</sup> between the English and Belgian Dutch names of the images in the MultiPic database (Duñabeitia et al., 2018).<sup>3</sup> The threshold for classifying items as cognates or non-cognates was set at .75, based on the similarity measure for automatic cognate identification described in Schepens, Dijkstra, et al. (2013). 40 images of objects whose names were Dutch–English cognates with phonological Levenshtein distance  $\geq .8$  between the translation equivalents were chosen as our cognate stimuli. Each object with a cognate name was paired with an object that had a non-cognate name, with all non-cognate objects having a phonological Levenshtein distance  $< .75$  between the English and Dutch translation equivalents.<sup>4</sup>

<sup>2</sup>Levenshtein distance was defined by Schepens, Dijkstra, et al. (2013) as  $1 - \text{distance} \div \text{length}$ , with *distance* being the minimum number of insertions, deletions and substitutions, and *length* being the maximum length of the two translation equivalents. We used a normalisation constant of 5.

<sup>3</sup>The Dutch name listed in MultiPic for the cognate object *sock* was changed from *kous* to *sok* to increase the form overlap.

<sup>4</sup>Due to an initial issue with the computation of the similarity measure, one item (*fox – vos*) was classified as a non-cognate despite having a normalised phonological Levenshtein distance of .825. Since the orthographic distance was .333, the item was considered sufficiently dissimilar to be included as a

**Table 5.2.** Characteristics of object names and images by cognate status.

	Cognate status	
	Cognate	Non-cognate
<b>Object name</b>		
Frequency	4.41 (0.54)	4.34 (0.50)
Concreteness	4.77 (0.28)	4.82 (0.21)
Orthographic length	5.10 (1.58)	5.42 (1.38)
Phonological length	4.35 (1.55)	4.20 (1.24)
Syllables	1.40 (0.70)	1.50 (0.60)
Surprisal	9.82 (2.70)	9.61 (3.16)
Phonological distance	.92 (.06)	.62 (.08)
Orthographic distance	.74 (.19)	.13 (.13)
<b>Object image</b>		
Visual complexity	2.69 (0.49)	2.82 (0.45)
Name agreement English (%)	84.90 (17.50)	86.20 (17.20)
Name agreement Dutch (%)	85.10 (17.00)	82.70 (18.50)

*Note.* Standard deviations in parentheses.

Paired *t*-tests were conducted to ensure cognate and non-cognate target object names were not significantly different with regard to word frequency (SUBTLEX-UK; van Heuven et al., 2014), concreteness (Brysbaert et al., 2014), orthographic length, number of phonemes (CLEARPOND; Marian et al., 2012), and visual complexity of their drawings, with all *ps* > .09. Additionally, the name agreement between cognate and non-cognate objects was not significantly different in English or in Dutch (*ps* > .6). Descriptive statistics of the lexical characteristics of the stimuli are provided in Table 5.2.

Each cognate/non-cognate object pair (e.g., *pipe* – *pijp* / *wallet* – *portemonnee*) was paired with a sentence such that both objects were appropriate referents of the main verb, as in the sentence *The man wanted to buy a new ...*. The target word was always the last word of the sentence. Each sentence was paired with a set of four coloured images from MultiPic: two plausible target objects (e.g., a pipe and a wallet) and two

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non-cognate in our stimuli.

**Table 5.3.** Example sentence and objects by object type and cognate status.

Sentence	Target objects		Unrelated objects	
	Cognate	Non-cognate	Cognate	Non-cognate
<i>The man wanted to buy a new ...</i>	Pipe ( <i>Pijp</i> )	Wallet ( <i>Portemonnee</i> )	Priest ( <i>Priester</i> )	Plumber ( <i>Loodgieter</i> )

*Note.* Dutch translations in parentheses.

unrelated objects (e.g., a priest and a plumber). Each target object pair was reused so that they also appeared as unrelated objects, and as such the names of the unrelated pairs were also a cognate and a non-cognate. Example stimuli are shown in Table 5.3. The full set of experimental stimuli can be found in Appendix B.

To assess the predictability of the objects given the sentence and main verb, we extracted surprisal values from GPT-2 for the names of each object given the sentence using the *PsychFormers*-package in Python (Michaelov & Bergen, 2022). Surprisal values between cognate and non-cognate target objects were not significantly different ( $p = .667$ ) and were significantly different between targets and unrelated objects ( $p < .001$ ).

Additionally, two object selection pre-tests (following Corps et al. (2022)) were conducted online. In each pre-test, 10 Dutch–English bilingual participants ( $M_{age} = 24.75$  years, 7 male) were presented with the sentences without the target word, as well as the four images of the objects. In the first pre-test, participants were instructed to select which of the four objects they believed someone producing the sentence could refer to next, with the option to select as many pictures as they liked. This test was conducted to confirm that both target objects (and none of the unrelated objects) were appropriate referents of the verb. Cognate and non-cognate target pictures were selected 97% and 95.8% of the time, respectively. The second test required participants to choose only one object to ensure that the target objects were equally plausible referents of the verb. Overall, 51% chose the non-cognate target and 48.2% the cognate target object. There were no significant differences between cognates and non-cognates in either pre-test (both  $ps > .579$ ). The unrelated objects were selected less than 1.5% of the time in both tests.

The experimental sentences were recorded in a sound-attenuated studio by a female native British English speaker (at 48 kHz, 16-bit). The average speech rate was 2.3

**Table 5.4.** Descriptive statistics of experimental sentences by list and cognate status of target word.

	List		Cognate status	
	1	2	Cognate	Non-cognate
Syllables	10.5 (1.7)	9.9 (1.9)	10.3 (1.8)	10.1 (1.8)
Speech rate (syll/sec)	2.4 (0.4)	2.3 (0.4)	2.4 (0.4)	2.3 (0.4)
Duration (ms)	4369 (235)	4372 (235)	4367 (239)	4375 (231)
Verb onset (ms)	1897 (146)	1904 (161)	1898 (156)	1904 (151)
Verb offset (ms)	2501 (201)	2497 (204)	2497 (208)	2501 (198)
Target onset (ms)	3694 (240)	3720 (225)	3709 (225)	3705 (242)

*Note.* Standard deviations in parentheses.

syllables per second (computed in PRAAT with a script by de Jong et al. (2021)). The speaker was instructed to maintain a natural tone with slight pauses between phrases. Each sentence was recorded in two versions: one ending with the cognate target and the other with the non-cognate target. One sentence from each pair was randomly assigned to one of two lists, such that for each list, the sentences ended with a cognate target half the time and a non-cognate target the other half. The audio was trimmed using Audacity (Version 3.4.2; Audacity Team, 2023) to remove silences at the start and end, and the cognate/non-cognate sentence pairs were aligned by adjusting pauses between phrases to match the descriptive sentence statistics shown in Table 5.4. The sentences consisted of 8–10 words ( $M = 8.5$  words,  $SD = 0.6$ ) and averaged 4.4 seconds in length. There were no significant differences in mean duration, speech rate, verb onset, verb offset, or target onset across lists or target types (all  $ps > .05$ ).

### 5.2.3 Design

We manipulated cognate status (cognate vs. non-cognate) within participants and between items. Pictures from each condition were presented in the same display, rather than displaying one condition per trial, because the research question explores whether L1 and L2 information compete for activation (Ito & Knoeferle, 2023).

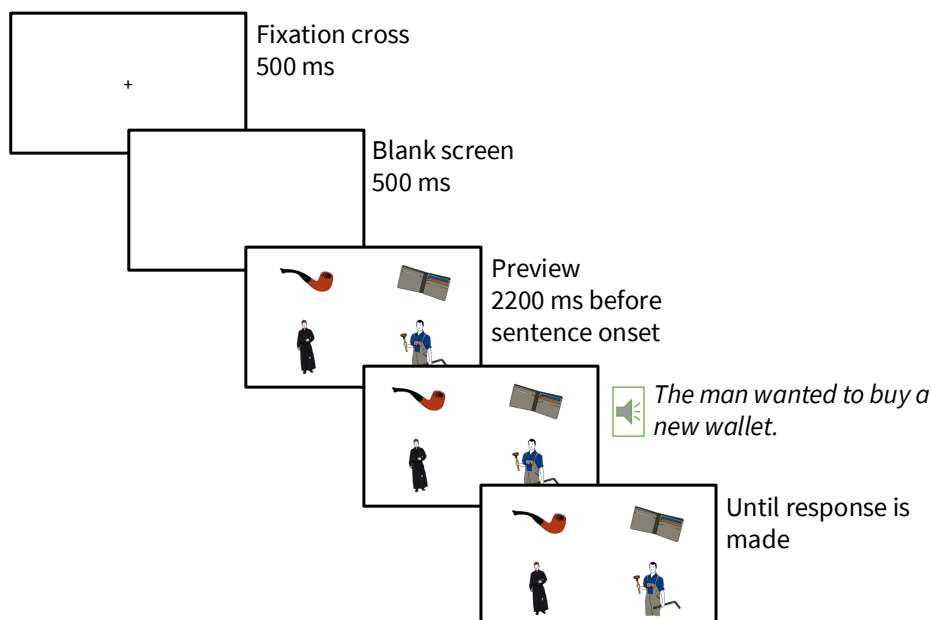
Participants were randomly assigned to one of two lists. The lists differed by which target word (cognate or non-cognate) was uttered at the end of the sentence. The

order of trials was randomised individually for each participant. In each list, the 24 possible permutations of image positions (e.g., cognate target top right, non-cognate target top left, unrelated objects bottom right and left) were randomly assigned across trials with sentences ending in the cognate and non-cognate target words (12 each). For the remaining trials, a random layout combination was chosen from the 24 possible combinations and assigned to trials such that they were not repeated within a trial type (i.e., the 12 combinations used for the trials with sentences ending with a cognate were assigned to non-cognate trials, and vice versa for the trials with sentences ending with a non-cognate). Additionally, layout combinations were balanced such that each object type appeared equally frequently (five times) in each of the four quadrants.

#### 5.2.4 Procedure

Participants were tested at Ghent University. They were seated in front of a computer screen with a resolution of  $1024 \times 768$  pixels and a viewing distance of roughly 70 cm. Before the eye-tracking experiment, participants completed an object familiarisation task, where they viewed the 80 experimental images presented one by one. Object names were presented visually along with the images in English in one block, and in Dutch in a separate, identical block. The order of these blocks was counterbalanced: half of the participants saw the Dutch block first, and the other half saw the English block first. Participants were instructed to associate the names with the images so that they could name them later. After each block, participants were shown the objects one by one and asked to type the names of each object in a naming task, with only one attempt allowed for each name.

The eye-tracking experiment began with a nine-point calibration procedure, and the participants' eye movements were recorded using an EyeLink 1000+ eye-tracker (SR Research Ltd.) sampling from the right eye at 1000 Hz. Participants were instructed to listen to the sentences while viewing the pictures and to click on the object mentioned last by the speaker after each sentence finished. The experiment started with four practice trials, and participants were given the opportunity to ask any questions after the practice session. A drift check was performed before each trial. Each trial began with a fixation cross followed by a blank screen, each presented for 500 ms. The four pictures ( $200 \times 200$  pixels each) were then displayed in each quadrant of the screen for 2200 ms before the sentence onset. The pictures remained on the screen until the participant clicked on one of the objects. The preview duration was set to 2200 ms to



**Figure 5.1.** Trial procedure for the eye-tracking experiment.

ensure participants had enough time to process every image on the screen and to make our method comparable to Dijkgraaf et al. (2017). The structure of the eye-tracking experiment is shown in Figure 5.1.

After the main experiment, participants completed a language history questionnaire adapted from the LEAP-Q questionnaire (Marian et al., 2007), the English version of the LexTALE vocabulary test (Lemhöfer & Broersma, 2012), and a translation task where they translated the predictive verbs from the experimental sentences into Dutch.

### 5.3 Results

The data was analysed in *R* (R Core Team, 2021) using *lme4*-package (Bates et al., 2015). Fixation proportions (i.e., the percentage of looks to each of the objects) were divided into 50 ms bins from 1000 ms before verb onset until 200 ms after target onset (the 200 ms delay was added to the target word onset to allow for the time it takes to plan a saccade, as per Matin et al. (1993)). All participants fixated within the interest areas at least 20% of the time within the predictive time window (200 ms after verb onset to 200 ms after target word onset). Blinks (1.5% of the samples) and off-screen fixations (0.4% of the samples) were included in the total sample count when computing the proportion of looks to the objects. Data points where all samples consisted of a blink

or out-of-screen sample were excluded from the analysis (1.1% of the data). The mean accuracy in the object naming task in English was 95.7% ( $SD = 3.5$ ) and in Dutch, it was 96.5% ( $SD = 3.1$ ). Trials with target objects that were named incorrectly in either the Dutch or English naming tasks were removed from the eye-tracking data (14% of the samples), as were trials where participants incorrectly translated the predictive verb in the translation task (1.4% of the remaining samples). Additionally, trials where participants clicked on the incorrect target image were excluded (0.2% of the remaining samples). All participants had more than 97% accuracy in the object selection task ( $M = 99.7\%$ ,  $SD = 0.8$ ).

Fixation proportions toward each of the objects were transformed using the empirical logit formula (Barr, 2008):

$$\text{elogit}(x) = \log \left( \frac{x \cdot 50 + 0.5}{(1 - x) \cdot 50 + 0.5} \right) \quad (5.1)$$

where  $x$  is the observed fixation proportion and 50 the number of samples. The two categorical predictor variables — object type (target vs. unrelated object) and target type (cognate vs. non-cognate object name) — were sum-coded. Following Barr (2013), we first fit a maximal model to the data, including random intercepts for participant, sentence, and target image, as well as random slopes for the fixed effects of interest. If the model produced convergence issues, we first attempted to refit it using the *allFit*-function from the *afex*-package (Singmann et al., 2024). If the model still failed to converge, we simplified the random effects structure by removing the correlation term between slopes and intercepts, and if necessary, progressively removing slopes and then intercepts with the least variance until the model converged (Matuschek et al., 2017).

The time-course of predictive looks toward each object type is plotted in Figure 5.2. We first tested whether verb-mediated prediction occurred and whether this effect was present only during the predictive time window (200 ms after verb onset to 200 ms after target word onset) and not in the pre-verb time window (1000 ms before verb onset until verb onset). In the predictive time window, there were significantly more looks toward target objects relative to unrelated objects ( $b = -1.74$ ,  $SE = 0.02$ ,  $t = 110.14$ ),<sup>5</sup> a difference that was not significant in the pre-verb time window ( $b = 0.16$ ,  $SE = 0.18$ ,  $t = 0.92$ ),<sup>6</sup> suggesting that participants predicted the upcoming referent after verb onset. To determine the mean onset of predictive looks, we conducted a divergence point

<sup>5</sup>Full mixed-effects model structure in  $R$ , fit with the *nlminbwrap*-optimiser:  $\text{log\_proportion} \sim \text{object\_type} + \text{list} + (1|\text{participant})$

<sup>6</sup>Full mixed-effects model structure in  $R$ , fit with the *nlminbwrap*-optimiser:  $\text{log\_proportion} \sim \text{object\_type} + \text{list} + (\text{object\_type}|\text{participant}) + (\text{object\_type}|\text{sentence}) + (\text{object\_type}|\text{target\_image})$

analysis (Stone et al., 2021), which showed that the difference in looks between target vs. unrelated objects arose at 139 ms ( $CI[50, 350]$ ) after verb onset.

Next, the data were subset to include only fixation proportions to the two target objects, in order to test whether there was an effect of cognate status of the target object during the predictive time window. The effect of target type (cognate vs. non-cognate) was not significant, providing no evidence that the cognate status of the upcoming input affects L2 prediction ( $b = -0.08$ ,  $SE = 0.19$ ,  $t = -0.42$ ).<sup>7</sup>

We conducted an exploratory analysis where we included L2 English proficiency, as measured by the LexTALE test, and its interaction with cognate status as predictors.<sup>8</sup> Neither the effect of target type ( $b = -0.08$ ,  $SE = 0.19$ ,  $t = -0.43$ ) nor its interaction with proficiency ( $b = -0.01$ ,  $SE = 0.01$ ,  $t = -0.66$ ) were significant. In a second exploratory analysis, we quantified the cognate status of target object names using their normalised phonological Levenshtein distance. This analysis found no significant effect of phonological similarity on predictive looks to the target objects ( $b = -0.34$ ,  $SE = 0.73$ ,  $t = -0.47$ ).

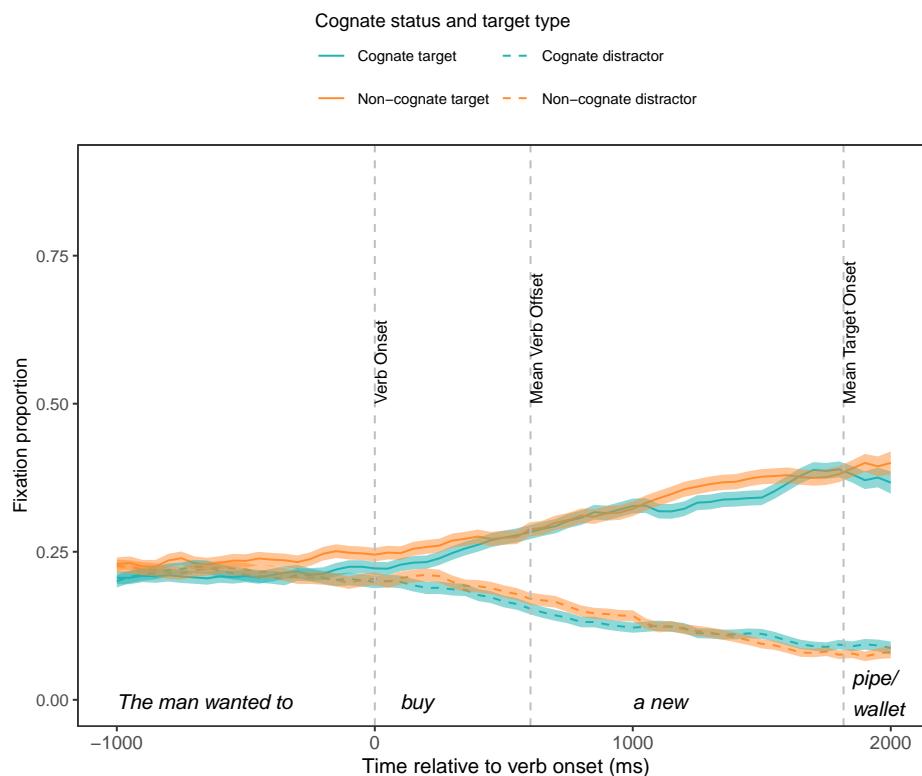
We also inspected the reaction times for clicking the targets, and found no significant difference between the reaction times to cognate ( $M = 1007$  ms,  $SD = 330$ ) and non-cognate ( $M = 990$  ms,  $SD = 332$ ) targets ( $b = -15.44$ ,  $SE = 18.05$ ,  $t = -0.86$ ).

## 5.4 Discussion

We observed an effect of verb-mediated prediction, with target objects that were appropriate referents of the verb receiving a higher proportion of looks compared to unrelated objects during the predictive time-window. This effect became apparent 139 ms after verb onset. No significant differences were observed between the proportion of looks toward cognate vs. non-cognate target objects, and the effect was not modulated by L2 proficiency or the degree of phonological similarity between the Dutch and English target object names. Our results provide further evidence that bilinguals can predict upcoming semantic information in their L2. However, they also suggest that overlapping information between the L1 and the L2 on the form level in the input to be predicted does not affect the prediction process.

<sup>7</sup>Full mixed-effects model structure in  $R$ , fit with the *bobyqa*-optimiser:  $\log\_proportion \sim target\_type + list + (target\_type|participant) + (target\_type|sentence) + (target\_type|target\_image)$

<sup>8</sup>Full mixed-effects model structure in  $R$ , fit with the *bobyqa*-optimiser:  $\log\_proportion \sim lextale\_score*target\_type + list + (target\_type|participant) + (target\_type|sentence) + (target\_type|target\_image)$



**Figure 5.2.** Time course of fixation proportions to the two target and two unrelated distractor objects by cognate status (cognate vs. non-cognate). Ribbons indicate standard errors.

There are three potential interpretations for our findings. First, it is possible that bilinguals do not pre-activate any information from the L1 when predicting in the L2. If this is the case, L2 prediction is essentially language-selective, where the pre-activation of lexical representations is restricted to within-language representations. Second, it is also possible that L2 prediction is language-selective on the phonological level, meaning that lexical representations on other levels (e.g., morphological/syntactic or orthographic representations) could be non-selectively pre-activated during prediction. Lastly, it could be that bilinguals do not predict phonological features of upcoming input at all when using their L2.

Our findings contrast with theoretical proposals that cognates would facilitate predictive processing. Theories of L2 prediction propose that prediction in an L2 may be less robust than in an L1 due to factors such as reduced language exposure (Dijkgraaf et al., 2017, 2019). This limited exposure can lead to slower activation of form and semantics during prediction, limiting predictive processing. As bilinguals generally encounter cognates more frequently than non-cognates, we expected the prediction

of cognates to be easier or faster than that of non-cognates because of qualitative differences between their lexical representations. Additionally, difficulties associated with L2 production along with possible interference from the L1 may add cognitive demands that interfere with predictive processing (Ito et al., 2018). According to this explanation, we also expected facilitation for cognate prediction, because form-level information overlaps between the L1 and L2 for cognates but not for non-cognates, which would ease production and/or reduce the L1 interference. However, the results of this study suggest that cognate status does not influence predictive looks of input that is being predicted.

The modality of our study may offer further insight into these results. While many studies have shown cognate facilitation in written word recognition and language production, few studies have explored the effect in an auditory setting. The findings in auditory cognate recognition are mixed. While some studies report facilitation from phonological similarity for certain measures like signal detection (Frances et al., 2021), most studies have found null or inhibitory effects, with orthographic and phonological similarity playing an inhibitory role both within the same modality, but also across modalities (Cornut et al., 2022; Frances et al., 2021; Guediche et al., 2020). Although our study was conducted in the auditory domain, it remains unclear whether these findings can explain our results, because we are asking what happens *before* the auditory input is processed. This issue is further complicated by the possibility that the production system may also be engaged during prediction (Pickering & Garrod, 2013), making it uncertain whether results from recognition or production studies should inform our expectations of cognate facilitation or inhibition.

Our materials consisted of cognates embedded in sentence contexts, unlike the aforementioned studies on auditory cognate processing, which concerned single-word recognition. Evidence from reading studies show that high contextual constraint (i.e., high cloze) reduces or eliminates cognate effects (see e.g., Lauro & Schwartz, 2017, for a review). Therefore, it could be that the somewhat constraining sentence contexts in our stimuli eliminated any cognate effects, but it would be challenging to explore prediction without some constraint on the upcoming input. Additionally, as mentioned in Footnote 1 in the Introduction, the meta-analysis of Lauro and Schwartz found that the overall effect of cognate status was significant even in highly constraining sentence contexts.

Additionally, the cloze probability of our sentences may have influenced our ability to detect phonological form prediction. For example, Ito (2024) found that predictive

phonological competitor effects in L1 speakers are modulated by cloze probability, with larger effects when cloze probability is higher. Similarly, Ito et al. (2018), who did not find such effects in L2 speakers with relatively high cloze probability (89%) sentences, point out the possibility that due to a reduced exposure to the L2, cloze probability is likely lower for L2 speakers than it is for L1 speakers. As a result, L2 speakers might have more difficulty using contextual information for prediction than L1 speakers. It is important to note that we examined phonological prediction by exploring effects at the target objects rather than phonological competitors. Our results are still in line with previous research, since no effects of overlapping phonology were obtained, but it is possible that a sufficiently high cloze probability could affect the prediction of form. Future research should investigate cognate effects in spoken word recognition within context, as well as in predictive processing.

Language proficiency and experience could further explain our results in that cognate effects are often modulated by proficiency in the target language, with increased proficiency leading to smaller effects in on-line processing (Andras et al., 2022; Fricke, 2022; Libben & Titone, 2009; Starreveld et al., 2014). Our participants were fairly proficient in the L2 English, with an average LexTALE score of 81.8. It is possible that their level of proficiency was too high to elicit any cognate effects. Ito et al. (2024) found that predictive processing in lower proficiency L2 speakers was facilitated when the predictive verb was a cognate vs. when it was not, whereas higher proficiency participants showed facilitated prediction when the verb was a non-cognate. Similarly, previous research has shown that increased L2 proficiency leads to a smaller influence of L1 information. For instance, Hopp and Lemmerth (2018) found that advanced L2 learners were native-like in the prediction of gender, whereas less proficient L2 speakers only predicted gender features when they syntactically overlapped with their L1. However, in our study, no interaction between proficiency and cognate status was found, leaving open the possibility that the level of proficiency in our participants was too high to detect an effect.

A potential confound of our study is the presentation of both target objects in the same visual display. One may query whether a cognate effect would have emerged if only one target object had been presented along with unrelated objects instead. However, it seems unlikely that our chosen design would have completely eliminated cognate effects, if present. Moreover, our design allowed us to balance the cognate status of the target and unrelated objects, which could be challenging with a design involving only one target object.

Finally, the language context of our task may also have played a role. It is possible that a task that directly engages both languages (i.e., a dual-language context) would induce cognate effects, as previous studies have shown that language context may modulate cross-language effects in on-line processing (e.g., Wu & Thierry, 2010). However, while our eye-tracking task was conducted in a one-language context, the object familiarisation and naming tasks immediately preceding the eye-tracking experiment engaged both languages, likely activating both L1 and L2 representations of the targets. Our results may have been different in a two-language task, but are compatible with the assumption that if there is no bottom-up input to inform that information from the L1 is relevant, pre-activation of input could thus be language selective.

In conclusion, while some theories suggest that cognates should facilitate prediction due to their shared form between languages, our results indicate that this facilitation might not occur, at least when information is shared in the predictable input. This is in line with accounts such as Ito et al. (2018), according to which there is no prediction of form in L2 processing, suggesting that L2 prediction might rely more on semantic than form-based prediction.

# Chapter 6

## Discussion and General Conclusions

The aim of this thesis was to explore the degree of non-selective activation in bilingual and multilingual lexical access, in order to understand the extent to which the word recognition system can be constrained to operate selectively. Additionally, the thesis addressed alternative hypotheses for cross-language effects in non-native language comprehension, with a particular focus on the cognate facilitation effect, incorporating learning mechanisms to explain the effects. These questions were investigated through a combination of one theoretical review focusing on learning vs. on-line non-selective activation accounts of cognate effects in comprehension and production; one computational study examining cognate effects in relation to language exposure and word frequency in bilingual sentence comprehension; and two behavioural studies, one of which explored how language learning experience in trilinguals affects cognate processing, and the other investigated whether activation is non-selective in predictive processing. Together, these studies addressed whether evidence from cognate processing shows that lexical representations are consistently activated non-selectively across languages, or if cross-language effects can instead be attributed to mechanisms employed during the process of learning.

In Chapter 1, I reviewed the most influential models of bilingual word recognition, the BIA and BIA+ models (Dijkstra & van Heuven, 1998, 2002; Dijkstra, van Heuven, & Grainger, 1998; Grainger & Dijkstra, 1992), along with the evidence that led to their development. This evidence consisted of single-word recognition experiments in one- and two-language contexts, and demonstrated various effects mostly focused on the role of cross-linguistic form similarities in processing, like cognate and interlingual homograph effects, as well as cross-language neighbourhood effects. Consequently, the models assume that representations in the bilingual word recognition are activated non-

selectively. These experiments also showed that task demands (e.g., single-language vs. general lexical decision) and stimuli list composition (e.g., whether words from only one or two languages were presented) can modulate cross-language effects. Whereas the BIA model allows for some constraint on non-selectivity through top-down activation from the language nodes, its successor, the BIA+ model, ascribes any evidence of selective activation to the task/decision system instead.

The development of the BIA, BIA+, and MULTILINK models and their vigorous testing with empirical studies has been a remarkable feat, and they are each in their own useful models of bilingual word recognition. However, as they are models adapted from the monolingual domain, they fail to capture two crucial aspects: learning and context. Arguably, these matter more for word recognition in bilinguals, as we saw in Chapter 1, where I discussed studies that have demonstrated that global and local context, as well as proficiency (i.e., learning) can constrain bilingual word recognition to become like monolingual word recognition, in the sense that no cross-language effects are observed. This could mean that, at least in some cases, representations in one language are activated selectively. For example, we saw the effects of context in studies showing that early bilingual eye movements matched those of monolinguals when bilinguals read interlingual homographs (Hoversten & Traxler, 2016) or code-switches (Hoversten & Traxler, 2020), suggesting that context can constrain word recognition to become selective. We also saw effects of learning, in that L2 proficiency can reduce or eliminate cross-linguistic effects, like cognate facilitation (Libben & Titone, 2009), or cross-language neighbourhood effects (Mulder et al., 2018). Following up on these studies, in my thesis I have further investigated how context and learning has an effect on non-selective activation, as I will explain below.

To evaluate the assumptions of the aforementioned models, I further reviewed recent studies of cross-language effects both in isolation and in sentence context, with a focus on those that have found evidence that lexical access in word recognition may be selective. This evidence also consisted of studies investigating interlingual homograph and cross-language neighbourhood effects, as well as studies exploring the activation of translation equivalents, processing of code-switched input, and the contribution of language membership and sublexical cues on recognition. This review showed that there is ample evidence that lexical access can be selective in bilinguals. Furthermore, the review explored how some of the evidence, which is generally used to support the claim that activation is non-selective, can also be interpreted from a learning perspective. A learning approach allows for a more dynamic role for non-selective activation, by

assuming that it occurs during learning, but not necessarily when proficiency in a non-native language increases. With this in mind, I now move on to assess each research question in turn to present the contributions of this thesis.

## **6.1 How Are the Representations of Native and Non-Native Language Words Influenced by Learning?**

As discussed in Chapters 1 and 2, cross-linguistic effects related to form similarities can be explained through learning-based accounts, such as the framework proposed by Costa et al. (2017). This approach accounts for processing differences between cognates and non-cognates, as well as interlingual homographs and language-unique words, without assuming non-selective activation during on-line processing. Similarly, their approach can explain how findings that can be interpreted as non-selective activation, such as the ease or difficulty in processing second language (L2) translations of native language (L1) homonyms or L1 words that partially overlap in their form in single-language contexts (Elston-Güttler, Paulmann, & Kotz, 2005; Elston-Güttler & Williams, 2008; Thierry & Wu, 2007), without requiring on-line non-selective activation.

Chapter 2 presented the orthodox on-line explanation, rooted in the MULTILINK model, which unifies the BIA, BIA+ models, and the RHM, of a well-evidenced cross-language effect: the cognate facilitation effect. This explanation was contrasted with the account proposed by Costa et al. (2017). According to this alternative account, representations co-activated during learning form connections through Hebbian learning. Because the form overlap of cognate translations is particularly salient to learners, cognates become more prominently represented in the mental lexicon compared to non-cognates, which explains their facilitated processing. Within this framework, it is also possible that non-selective co-activation decreases or ceases altogether as proficiency in the new language increases.

The chapter further refined this hypothesis by specifying what happens during processing: due to their enhanced representations, cognates require less evidence to reach the threshold for successful identification than non-cognates, in a similar manner to how higher-frequency words are thought to require less evidence for recognition compared to lower-frequency words within a single language. In contrast, on-line accounts assume that cognate representations are activated to a higher degree than those of non-cognates, driven by converging and feedback activation between non-selectively

co-activated representations. Thus, for cognate processing, the main difference between the two accounts is whether activation occurs faster and to a higher degree for cognates than non-cognates (on-line account), or whether less activation is required (learning account).

In Chapter 2, I further evaluated whether current evidence on cognate processing in comprehension and production is compatible with the learning account contra the on-line account. The chapter concluded that the evidence is compatible with both accounts and that cognate effects alone do not demonstrate non-selective lexical access, nor learning effects. However, some evidence in particular favours a learning account, such as the finding that cognates are learned better than non-cognates (e.g., de Groot et al., 2000; de Vos et al., 2019; Lotto & de Groot, 1998), and that cognate effects and word frequency effects show similar temporal patterns in neurophysiological measures (Strijkers et al., 2010). Of course, a learning account that assumes co-activation during learning is also compatible with an on-line account that assumes non-selective co-activation during processing. However, the strength of a learning explanation for cognate effects (as well as other cross-linguistic effects) lies in its dynamic view of how learning interacts with lexical representations, which allows for flexibility in interpreting the effects.

The question of how learning interacts with lexical representations was specifically tested in the experiment in Chapter 4. In this experiment, I investigated whether the language of instruction (i.e., the language through which a new language is acquired) modulates the cognate effect, in that it would only occur between the two languages involved in learning. The hypothesis was based on the learning account of Costa et al. (2017), with the assumption that the form similarities of cognate translations would be more salient for cognates between the two languages used during learning than for cognates between the new language and another known language not used during learning. Thus, co-activation during learning, which leads to the enhanced representations of cognates, would be stronger for the former type of cognates than the latter.

To test this hypothesis, Dutch–French–English and French–Dutch–English trilinguals, who had learned a third language, English, through either their L1 Dutch or L1 French performed a classic lexical decision task. This task included English words that were cognates between Dutch and English, between French and English, and their matched non-cognate controls. The findings supported the learning hypothesis in that differences in lexical decisions were found only for cognates between the target

language and the language of instruction. However, this pattern emerged mainly in the group who learned English through Dutch, and we did not observe a conventional cognate effect with faster lexical decisions for cognates than non-cognates, even for cognates between the languages involved in learning. Additionally, the participants' language of instruction was the same as their L1, leaving open the possibility that the observed cognate effects were driven by form overlap with the stronger L1 rather than co-activation with the language of instruction.

A different learning hypothesis was explored in Chapter 3, where the role of the cumulative word frequencies of cognates across a bilingual's languages was investigated using neural language models. Here, cognate facilitation was observed in models simulating unbalanced bilinguals, and the facilitated processing of cognates was explained by their cumulative frequencies in the training data. Although the learning mechanisms of recurrent neural network (RNN) language models are not well understood, and their relationship to human learning mechanisms is even less clear, the findings presented in this chapter demonstrate that learning mechanisms can in principle contribute to cognate facilitation in bilinguals. Specifically, they lend support to the cumulative frequency hypothesis (Midgley et al., 2011; Voga & Grainger, 2007), which posits that the facilitated processing of (identical) cognates relative to non-cognates occurs because cognates are encountered more often, as their form and meaning exist in both of a bilingual's languages. Here, too, the cognate facilitation effect can be seen as a frequency effect, with cognates behaving like higher-frequency words within a language and non-cognates behaving like lower-frequency words.

More specifically, the computational experiment in Chapter 3 showed that neural language models trained on two languages exhibit patterns similar to those observed in human bilinguals in relation to cognate facilitation: lower surprisal (i.e., ease of processing) was observed for cognates compared to non-cognates. The magnitude of this effect was modulated by model perplexity in the L2, which reflects its ability to predict the L2. Models with lower L2 perplexity (i.e., better prediction ability) exhibited a smaller difference in surprisal between the two word types. This finding is analogous to the effect of L2 proficiency on cognate facilitation in bilinguals, where more proficient L2 speakers show a reduced effect (e.g., Bultena et al., 2014; Libben & Titone, 2009; Pivneva et al., 2014). Lastly, the differences in surprisal for the two word types were better explained by the actual cumulative (i.e., summed) word frequencies of the target words in the training data than by their cognate status, supporting the hypothesis that the ease of processing for cognates is due to their higher frequency

compared to non-cognates. Overall, the findings presented in this chapter offer further support for the hypothesis that the cognate facilitation effect is driven by differences in word frequency.

## 6.2 Do Bilinguals Predict in Their L1 When Using Their L2?

Chapter 5 presented a different perspective on non-selective activation in bilingual language processing within the context of linguistic prediction. The experiment in Chapter 5 showed that there were no differences in the time-course of prediction of cognates and non-cognates. This suggests that bilinguals do not predict in the L1 when using the L2. Therefore, although a null result and not conclusive evidence, the experiment shows no evidence for non-selective pre-activation during L2 prediction, or in other words, how quickly or accurately a concept is predicted does not depend on whether its word form has cross-linguistic overlap. It could be that prediction only occurred on the conceptual level, because conceptual representations are thought to be shared in the bilingual mental lexicon. If this is the case, the study is not informative about the question of non-selective activation. But it could also be that word forms were pre-activated, albeit non-selectively, which is why no differences were observed between the two word types. In that case, the study is informative about the question of non-selective activation, suggesting that during L2 prediction, word forms are activated selectively, for instance through constraints on the language membership of the upcoming input set by the sentence context.

The findings from Chapter 5 suggest that bilinguals predict semantic information in an L2, but do not provide any evidence that they predict phonological information. These findings are in line with previous findings from e.g., Dijkgraaf et al. (2017), who found that bilinguals can use constraints posed by verb semantics to generate predictions in an L2, as well as Ito et al. (2018), who found no evidence of phonological prediction in an L2. One explanation for why no cognate effects were observed in L2 prediction can be found in Ito et al. (2024), who tested whether the cognate status of a predictable verb affects prediction of its referents, and found that only lower proficiency participants showed cognate effects, in that they predicted the upcoming referent faster when the predictable verb was a cognate than when it was a non-cognate. Although the experiment in Chapter 5 did not reveal any differences in cognate processing related to

participants' L2 proficiency, it could be that the group's overall proficiency in the L2 was too high to elicit any cognate effects.

### **6.3 Are Lexical Representations Consistently Activated Non-Selectively During Non-Native Language Word Recognition?**

As discussed in Chapters 1 and 2, current models of bilingual word recognition, such as the BIA+ and MULTILINK models, assume that activation in the word recognition system is *always* non-selective. While this assumption is consistent with by extensive evidence, I have shown in these chapters that this evidence can be reinterpreted from a perspective where the word recognition system can also operate selectively. Empirically, two lines of evidence support this conclusion.

First, studies suggest that both global and local language context can influence word recognition, enabling it to become selective. For example, semantically constraining sentence contexts can reduce or even eliminate cross-language effects, such as those observed with cognates or interlingual homographs (e.g., Hoversten & Traxler, 2016; Lauro & Schwartz, 2017). Chapter 5 adds to this body of evidence, as no cognate effects were observed in spoken sentence comprehension and L2 prediction. Additionally, language membership information derived from the global language context (Elston-Güttler, Gunter, & Kotz, 2005) or sublexical cues (e.g., Casaponsa & Duñabeitia, 2016; Hoversten et al., 2017) is another factor that helps constrain non-selective activation. Further investigation is needed to determine whether the inconsistent nature of cross-linguistic effects, particularly in contextual processing, is driven by the pre-activation of language tags, an assumption consistent with at least the BIA model (Dijkstra & van Heuven, 1998), or whether these effects are better explained by alternative mechanisms, for instance the learning mechanisms proposed by Costa et al. (2017, 2019) and discussed in Chapter 1 and 2.

Second, also language exposure and proficiency can constrain non-selective activation (Libben & Titone, 2009; Mulder et al., 2018; Schwartz & Kroll, 2006). The exact mechanisms that lead to these constraints are still a topic of debate. It could be that more proficient bilinguals are better at inhibiting the contextually irrelevant language (e.g., Biedermann et al., 2024). Or it could be that exposure-based learning mechanisms, including Hebbian learning principles and spreading activation can account for the

cross-linguistic effects, evidence of which we saw in Chapters 2, 3, and 4, suggesting a smaller role for non-selective activation. Another learning-based explanation is that of language exposure, compatible with the assumptions of the BIA/BIA+ models (as well as MULTILINK) that the resting level activation of L2 words increase with improved L2 proficiency and exposure, leading to ‘less prominent’ cross-linguistic effects (e.g., Mulder et al., 2018, p. 4). However, it is unclear to what extent this reduces or eliminates non-selective activation, an assumption of all three models. Lastly, it could be that more proficient bilinguals are better at using context to constrain cross-language activation (Ito et al., 2018).

In addition to the lack of evidence of non-selective activation in Chapter 5, we saw little evidence of the phenomenon in the other experiments presented in this thesis. In Chapter 4, there were no significant differences between cognates and non-cognates overall, and the cognate facilitation effect was only significant in interaction with the language of instruction. It is not clear how models assuming non-selective activation could explain these results. However, below I discuss some ways in which computational models could be used to capture the dynamic aspects of bilingualism, inspired by the methodology used in Chapter 3.

## **6.4 How Do Context and Language Proficiency Affect Bilingual Word Recognition?**

In Chapter 3, we observed that surprisal values for cognates vs. non-cognates, as well as the overall perplexity for each language in neural language models, are sensitive not only to the proportions of L1 and L2 training data but also the order in which this data is presented. Moreover, these patterns mirrored those found in human bilinguals: the learning conditions designed to simulate different types of bilingualism (e.g., simultaneous vs. sequential and balanced vs. unbalanced bilingualism) produced similar patterns in both the size and direction of the effects. For example, unbalanced sequential models exhibited larger cognate effects and higher L2 perplexity (i.e., lower “proficiency”) compared to balanced simultaneous models, which had smaller cognate effects and lower L2 perplexity (i.e., higher “proficiency”).

A comparison between the models in Chapter 3 and the participants in Chapters 4 and 5 sheds further light onto the role of proficiency and language exposure. The participants, like the models, acquired their L1 before L2/L3 English and reported

using English more than their L1. These characteristics align with the input conditions used to simulate the models that exhibited significant cognate effects. However, while cognate effects were observed in the models, they were not consistently observed in the behavioural data. One possible explanation is that the model with unbalanced L1/L2 input — mirroring the participants' language usage — did not learn the L2 well enough, assigning non-cognate L2 words low probabilities. Within this view, the cognate effect might arise not because cognates are facilitated, but because non-cognates (used as control words) are more difficult to process due to their lower frequencies in the input (Gollan et al., 2008, 2011; Pivneva et al., 2014; Titone et al., 2011; Whitford & Titone, 2012). For bilinguals with a sufficiently unbalanced exposure, these control words may be encountered too infrequently to be learned well.

Although these types of models may not directly address the question of non-selective activation, given the uncertainty that lexical co-activation occurs within these models, they still provide valuable insights into how cross-language effects manifest in a statistical learner implemented as a computational model.

An approach with neural language models trained on a next-word-prediction task not only integrates the effects of language exposure and context on non-selective activation but could also accommodate predictive processing. For example, as discussed in Chapter 1, code-switched words often lead to difficulties in processing (e.g., Altarriba et al., 1996; Hoversten & Traxler, 2020). A simple explanation of this is that an L1 word in an L2 context is improbable, yielding high surprisal. If lexical activation was fully non-selective, such processing difficulties would not be expected. The described approach accounts for this more effectively than static, single-word recognition models, such as the BIA/BIA+ and MULTILINK.

Recent research shows that, at least during native language processing, people make predictions across all linguistic levels, from semantic, syntax, words, and phonology, with higher-level predictions informing lower-level ones top-down (Heilbron et al., 2022). These findings do not rule out that language membership information could also inform the word recognition system in bilinguals, for instance through predictive processing, and thus constrain activation patterns, affecting lower-level predictions. This perspective may explain why no evidence of non-selective predictive activation was found in Chapter 5. It also supports the idea that L2 prediction is less likely to occur than L1 prediction, due to reduced exposure to L2 statistical regularities. However, reduced L2 prediction is also compatible with interactive models of bilingual word recognition, because increased cognitive demands caused by non-selective activation

may leave fewer resources for prediction (Foucart, 2021; Ito & Pickering, 2021; Ito et al., 2018).

Neural language models, such as the LSTM-model used in Chapter 3, are not necessarily the only viable approach. Various other models of bilingual lexical learning have been proposed, which account for non-selectivity, context and proficiency effects, or lexical organisation to different degrees. Notable examples include the developmental BIA model (BIA-d; Grainger et al., 2010), the Self-Organising Model of Bilingual Processing (SOMBIP; Li & Farkaš, 2002), and the SRN simulations of French (1998). Li and Xu (2023) provide an excellent review of how dynamic approaches to L2 learning have been or could be implemented.

The emphasis on the BIA/BIA+ and MULTILINK models in this thesis is due to their central role in research on bilingual (and multilingual) word recognition, as they are by far the most widely cited, and they have shaped much of the theoretical and empirical discourse. Given their influence, it is essential to critically evaluate their assumptions and address their limitations, particularly in accounting for learning and context effects. By exploring alternative explanations for non-selective activation in cross-linguistic effects, such as the learning-based framework proposed by Costa et al. (2017), this thesis contributes to broadening the theoretical landscape.

Learning-based accounts provide a compelling explanation for why certain lexical representations are more accessible than others, but they lack a detailed account of how these representations are activated during on-line comprehension. Thus, an important challenge remains: how do we reconcile learning-based accounts with on-line processing models of word recognition? One possible reconciliation lies the view of learning and processing as interacting components of the mental lexicon. For instance, learning may determine the baseline activation levels of lexical representations (e.g., by resulting in higher baseline activation levels for cognates than non-cognates, as suggested in Chapter 2), while processing models describe how these representations are activated on-line. These mechanisms are already implemented in the MULTILINK and BIA models, as their baseline activation levels are determined by (within-language) word frequency. Experimenting with between-language or cumulative frequencies would be an interesting test of the assumptions of these models as well as learning accounts. Advancing experimental work along these lines could help bridging these two perspectives and clarifying how experience changes lexical connectivity over time and how these connections are used during comprehension.

Finally, a significant challenge for all computational models of monolingual and

bilingual language processing is their adaptation to multilingual environments. Indeed, many people, such as 37% of the EU adult population (Eurostat, 2024), know three or more languages. Interactive activation models like BIA/BIA+ and MULTILINK are notable for capturing both monolingual and bilingual processing, enhancing their explanatory adequacy (Frank, 2021). Nonetheless, based on the findings in Chapter 4, I argue that it is equally crucial for a bilingual model to be adaptable to multilingual contexts. It remains unclear how well the bilingual interactive activation models would perform with the introduction of an additional language. Although theoretical accounts have been proposed for how they explain for instance cognate effects in trilinguals (Lemhöfer et al., 2004), both a lack of empirical evidence from trilingual word recognition and a lack of model specification for the trilingual case leaves many questions unanswered for the domain of multilingual word recognition and lexical access.

## 6.5 Concluding Remarks

This thesis contributes to our understanding of bilingual word recognition and sentence comprehension by challenging mainstream assumptions about non-selective activation. As demonstrated in this thesis, exposure-based learning mechanisms — including Hebbian learning principles, spreading activation, and repeated exposure — can account for the cognate facilitation effect, which suggests that further exploration into their role in explaining other cross-linguistic effects are necessary.

The work presented here also raises interesting questions for future research. For example: Does non-selective co-activation in lexical access and word recognition persist throughout the lifespan of a bilingual, or is it restricted to earlier stages of language learning? How can we incorporate learning mechanisms and context effects into our models of word recognition? Does non-selective activation occur only at early stages of word recognition, such as sub-lexical levels, but not during later lexical access? To what extent does information from the L1 help or hinder L2 processing, and how do the L1 and L2 interact during learning? Are the assumptions of non-selective activation applicable to predictive processing?

Together, the empirical and theoretical contributions of this thesis provide less mainstream explanations for cross-language effects, such as the cognate effect, and highlight the importance of reevaluating current most influential models to account for this new evidence. In the end, as Box (1979) aptly noted, ‘all models are wrong but

some are useful' (p. 202). The way forward, in my view, is to broaden our scope beyond just the mainstream models, to identify their strengths and weaknesses, and to focus on unifying the strengths of each model type. By doing so, we can better capture the complexity of bilingual and multilingual language processing and learning, in particular the interplay between languages. This is what I have attempted to do in this thesis: to challenge existing assumptions, explore less conventional explanations, and find new ways to investigate how learning mechanisms shape bilingual language processing.

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# Appendix A

## Supplementary Materials for Chapter 4

**Table A.1.** Target words used in the lexical decision experiment of Chapter 4 by cognate status with Dutch and French translations.

Cognates			Non-cognates		
Target	Dutch	French	Target	Dutch	French
<b>Dutch–English cognates</b>					
thief	dief	voleur	witch	heks	sorcière
dream	droom	rêve	truth	waarheid	vérité
wheel	wiel	roue	chest	borstkas	poitrine
ghost	geest	fantôme	curse	vloek	malédiction
apple	appel	pomme	knife	mes	couteau
bread	brood	pain	dress	jurk	robe
street	straat	rue	target	doel	cible
helmet	helm	casque	drawer	lade	tiroir
kettle	ketel	bouilloire	pillow	kussen	oreiller
weapon	wapen	arme	garlic	knoflook	ail
brother	broeder	frère	husband	echtgenoot	mari
shadow	schaduw	ombre	smile	glimlach	sourire
gold	goud	or	body	lichaam	corps
wall	wal	mur	bird	vogel	oiseau
wool	wol	laine	belt	riem	ceinture
lung	long	poumon	dirt	vuil	saleté

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Cognates			Non-cognates		
Target	Dutch	French	Target	Dutch	French
hell	hel	enfer	joke	grap	blague
meal	maal	repas	iron	ijzer	fer
blood	bloed	sang	horse	paard	cheval
heart	hart	cœur	coat	jas	manteau
liver	lever	foie	spoon	lepel	cuillère
spear	speer	lance	arrow	pijl	flèche
brain	brein	cerveau	cloud	wolk	nuage
ship	schip	bateau	skin	huid	peau
baker	bakker	boulangier	cheek	wang	joue
silver	zilver	argent	queen	koningin	reine
worker	werker	travailleur	bucket	emmer	seau
warmth	warmte	chaleur	bribe	steekpenning	pot-de-vin
hand	hand	main	town	stad	ville
storm	storm	tempête	nurse	verpleegster	infirmière
winter	winter	hiver	witness	ooggetuige	témoin
oven	oven	four	tail	staart	queue
wolf	wolf	loup	glue	lijm	colle
ladder	ladder	échelle	stairs	trappen	escalier
week	week	semaine	size	grootte	taille
gift	gift	cadeau	dust	stof	poussière
<b>French–English cognates</b>					
army	leger	armée	roof	dak	toit
poem	gedicht	poème	root	wortel	racine
voice	stem	voix	crowd	menigte	foule
beef	rundsvlees	boeuf	wire	draad	fil
farm	boerderij	ferme	duck	eend	canard
chair	stoel	chaise	beach	strand	plage
forest	bos	forêt	window	raam	fenêtre
garden	tuin	jardin	country	land	pays
bullet	kogel	balle	throat	keel	gorges
member	lid	membre	threat	dreigement	menace

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Cognates			Non-cognates		
Target	Dutch	French	Target	Dutch	French
mirror	spiegel	miroir	rabbit	konijn	lapin
enemy	vijand	ennemi	coward	schijterd	lâche
collar	kraag	collier	sleeve	mouw	manche
stomach	buik	estomac	cabbage	kool	choux
autumn	herfst	automne	spring	lente	printemps
airport	luchthaven	aéroport	bedroom	slaapkamer	chambre
vein	ader	veine	scar	litteken	cicatrice
sign	teken	signe	meat	vlees	viande
tribe	stam	tribu	trash	afval	poubelle
judge	rechter	juge	noise	lawaai	bruit
piece	stuk	pièce	woman	vrouw	femme
herb	kruid	herbe	silk	zijde	soie
court	rechtbank	cour	taste	smaak	goût
desert	woestijn	désert	monkey	aap	singe
branch	tak	branche	shark	haai	requin
missile	raket	missile	blanket	deken	couverture
issue	kwestie	issue	health	gezondheid	santé
angle	hoek	angle	owner	eigenaar	propriétaire
face	gezicht	face	girl	meisje	fille
muscle	spier	muscle	knight	ridder	chevalier
pigeon	duif	pigeon	wizard	tovenaar	magicien
statue	standbeeld	statue	spine	ruggegraat	colonne vertébrale
village	dorp	village	teacher	leerkracht	prof
habit	gewoonte	habit	delay	vertraging	retard
cage	kooi	cage	lawn	grasveld	pelouse
prison	gevangenis	prison	skirt	rok	jupe



## Appendix B

### Supplementary Materials for Chapter 5

**Table B.1.** Stimuli (sentences and names of objects) used in the visual world experiment of Chapter 5 by object type and cognate status, with Dutch translations in parentheses.

Sentence	Target objects		Distractor objects	
	Cognate	Non-cognate	Cognate	Non-cognate
The boy wanted to become a nice ...	doctor ( <i>dokter</i> )	teacher ( <i>leraar</i> )	butter	chicken
The woman wanted to wash the old ...	sock ( <i>sok</i> )	scarf ( <i>sjaal</i> )	elf	queen
The man wanted to buy a new ...	pipe ( <i>pijp</i> )	wallet ( <i>portefeuille</i> )	priest	plumber
The man decided to throw away the old ...	book ( <i>boek</i> )	key ( <i>sleutel</i> )	wolf	fox
The woman dreamt that she hunted an old ...	wolf ( <i>wolf</i> )	fox ( <i>vos</i> )	door	window
The woman dreamt that she was wearing an old ...	crown ( <i>kroon</i> )	dress ( <i>jurk</i> )	plant	rabbit
The woman decided to eat the old ...	butter ( <i>boter</i> )	chicken ( <i>kip</i> )	bomb	gun
The man decided to buy a new ...	computer ( <i>computer</i> )	suitcase ( <i>koffer</i> )	pilot	fireman
The girl decided to eat a nice ...	nut ( <i>noot</i> )	carrot ( <i>wortel</i> )	spear	coin

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Sentence	Target objects		Distractor objects	
	Cognate	Non-cognate	Cognate	Non-cognate
The man wanted to display the nice ...	spear ( <i>speer</i> )	coin ( <i>munt</i> )	princess	nurse
The woman decided to disarm the old ...	bomb ( <i>bom</i> )	gun ( <i>pistool</i> )	soup	sausage
The woman wanted to feed the nice ...	baby ( <i>baby</i> )	bird ( <i>vogel</i> )	boat	car
The woman wanted to buy a nice ...	rose ( <i>roos</i> )	necklace ( <i>ketting</i> )	doctor	teacher
The man wanted to repair the nice ...	boat ( <i>boot</i> )	car ( <i>auto</i> )	prince	wizard
The woman decided to eat the nice ...	fruit ( <i>fruit</i> )	meat ( <i>vlees</i> )	computer	suitcase
The woman decided to throw away the old ...	milk ( <i>melk</i> )	lemon ( <i>citroen</i> )	monster	witch
The boy dreamt that he became a good ...	pilot ( <i>piloot</i> )	fireman ( <i>brandweerman</i> )	pipe	wallet
The boy dreamt that he met a good ...	nun ( <i>non</i> )	hunter ( <i>jager</i> )	sock	scarf
The woman decided to feed the nice ...	elephant ( <i>olifant</i> )	monkey ( <i>aap</i> )	crown	dress
The woman wanted to open the old ...	door ( <i>deur</i> )	window ( <i>raam</i> )	baby	bird
The boy wanted to wear a nice ...	hat ( <i>hoed</i> )	belt ( <i>riem</i> )	dolphin	turtle
The girl wanted to eat the nice ...	soup ( <i>soep</i> )	sausage ( <i>worst</i> )	ball	doll
The woman decided to visit the old ...	bridge ( <i>brug</i> )	statue ( <i>standbeeld</i> )	rose	necklace
The man wanted to become a good ...	priest ( <i>priester</i> )	plumber ( <i>loodgieter</i> )	nut	carrot
The girl wanted to eat with the new ...	fork ( <i>vork</i> )	spoon ( <i>lepel</i> )	bridge	statue

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Sentence	Target objects		Distractor objects	
	Cognate	Non-cognate	Cognate	Non-cognate
The man decided to wear the new ...	helmet ( <i>helm</i> )	suit ( <i>kostuum</i> )	envelope	drawer
The woman decided to sell the old ...	piano ( <i>piano</i> )	horse ( <i>paard</i> )	nun	hunter
The man decided to repair the nice ...	lift ( <i>lift</i> )	fridge ( <i>koelkast</i> )	elephant	monkey
The child dreamt that she became a good ...	elf ( <i>elf</i> )	queen ( <i>koningin</i> )	fork	spoon
The man decided to escape from the old ...	cell ( <i>cel</i> )	prison ( <i>gevangenis</i> )	hat	belt
The boy dreamt that he listened to the old ...	saxophone ( <i>saxofoon</i> )	bagpipes ( <i>doedelzak</i> )	milk	lemon
The man wanted to sit on the nice ...	throne ( <i>troon</i> )	chair ( <i>stoel</i> )	fruit	meat
The child dreamt that he became a good ...	prince ( <i>prins</i> )	wizard ( <i>tovenaar</i> )	cell	prison
The child wanted to feed the nice ...	dolphin ( <i>dolfijn</i> )	turtle ( <i>schildpad</i> )	lift	fridge
The girl dreamt that she talked to a nice ...	princess ( <i>prinses</i> )	nurse ( <i>verpleegster</i> )	throne	chair
The woman wanted to care for the old ...	plant ( <i>plant</i> )	rabbit ( <i>konijn</i> )	saxophone	bagpipes
The child wanted to play with the new ...	ball ( <i>bal</i> )	doll ( <i>pop</i> )	helmet	suit
The child dreamt that he fought an old ...	monster ( <i>monster</i> )	witch ( <i>heks</i> )	book	key
The girl decided to open the old ...	envelope ( <i>envelop</i> )	drawer ( <i>lade</i> )	train	plane
The woman decided to board the new ...	train ( <i>trein</i> )	plane ( <i>vliegtuig</i> )	piano	horse