Using electrophysiological measures to track the mapping of words to concepts in the bilingual brain: A focus on translation

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Abstract

A central question in research on the bilingual mental lexicon is how second language (L2) learners map novel L2 word forms onto their respective meanings. For adult L2 learners, there is already extensive vocabulary knowledge in the first language (L1). How is the new information about L2 represented and processed relative to the L1? Which codes are engaged when translating words from one language into the other? Many previous reviews of the literature have considered these issues (e.g., Kroll & De Groot, 2005). Here we focus on a relatively new source of evidence drawn from recent studies using event-related potentials (ERPs). Because ERPs provide sensitive data about the timecourse of language processing in the brain, they provide a new opportunity to review the enduring debates in the literature concerning the initial mappings of word form to meaning by L2 learners and their consequences for proficient bilingual performance. We first review the theoretical framework that has shaped this debate, focusing primarily on the Revised Hierarchical Model (Kroll & Stewart, 1994). We then consider briefly the behavioral evidence that has been taken in the past literature to adjudicate alternative claims concerning the role of the L1 translation equivalent in processing L2. We then focus our discussion on recent Event Related brain Potential (ERP) studies that use variants of the translation task to examine the timecourse over which information about words in each of the bilingual's two languages becomes activated and available. We argue that converging evidence from electrophysiological studies provides a powerful tool for understanding L2 performance in both learners and highly proficient bilinguals and for resolving longstanding controversies in the literature.

[end abstract]

During the earliest stages of acquiring a new language, adult second language (L2) learners must first acquire a vocabulary in the L2 (e.g., De Groot & Van Hell, 2005). Early models of the bilingual lexicon asked how the newly learned L2 vocabulary is then fit into the lexical/semantic system that exists for words and concepts that are known in the native language, L1 (e.g., Potter, So, Von Eckhardt, & Feldman, 1984). Potter et al. (1984) proposed two models that differed in how directly learners might be able to connect new L2 words to their respective meanings. According to the Concept Mediation model, this process was assumed to be direct and available early in L2 acquisition. In contrast, the Word Association model characterized the mapping of L2 word forms to meaning as requiring mediation via the L1 translation, such that the meanings associated with L1 translations were assumed to be transferred to the L2. Potter et al. reported data supporting direct conceptual processing of words in the L2, even for relatively novice L2 learners. Subsequent research debated this conclusion and suggested that the two alternatives might characterize different stages of L2 proficiency, with the ability to bypass reliance on the L1 translation equivalent increasing as a learner becomes more proficient in the L2 (e.g., Chen & Leung, 1989; Kroll & Curley, 1988).

Kroll and Stewart (1994) proposed the Revised Hierarchical Model (RHM) to accommodate the developmental changes that occur during the initial stages of L2 learning. By effectively integrating the two models proposed by Potter et al. (1984), the RHM provided a framework in which the L1 translation equivalent might be engaged under some circumstances but once individuals acquire proficiency in the L2, direct conceptual processing also becomes possible. The history of these models and the research that has been performed to evaluate the predictions that they make about the trajectory of L2 development has been reviewed extensively in the recent literature (e.g., Kroll & Tokowicz, 2005; Kroll, Van Hell, Tokowicz, &

Green, 2010). Our goal in the present chapter is to evaluate a new body of evidence about the mapping of L2 words to concepts that has emerged in the past ten years with the increasing use of Event Related Potentials technique (ERPs) to measure brain activity. ERPs are more sensitive to the timecourse of processing, and particularly to the earliest stages of processing, than the behavioral methods that have historically been the basis upon which models of the bilingual lexicon have been evaluated. In what follows, we first provide a brief review of the theoretical debate and the behavioral evidence surrounding the RHM. We then turn our focus to the recent ERP studies that use variants of the translation task to examine the timecourse over which information about words in each of the bilingual's two languages becomes activated and available.

The Revised Hierarchical Model

The RHM is shown in Figure 1. The model assumes that there are strong connections between L1 words and their respective concepts. The L2 lexicon is characterized as being smaller and more weakly connected to conceptual information than the L1. Critically, the RHM assumes that conceptual information is largely shared across a bilingual's two languages (e.g., Francis, 2005). At the lexical level, there is hypothesized to be an asymmetry in the strength of connections between the two languages. Because L2 is thought to be dependent on L1 mediation during the very earliest stages of L2 learning, there are strong connections from L2 to L1 at the lexical level, but only relatively weak connections from L1 to L2. Over time, there may be feedback that creates a lexical association from L1 to L2, but the L1 will rarely be expected to rely on the L2 for access to meaning. As the individual becomes more proficient in the L2, the RHM assumes that the ability to directly access concepts for L2 words will strengthen, eventually reaching a level of lexical-to-conceptual mappings that are equivalent to those in L1 for bilinguals who are highly proficient and relatively balanced across the two languages.

Insert Figure 1 about here

Kroll and Stewart (1994) initially tested the predictions of the RHM in a translation production paradigm in which relatively proficient Dutch-English bilinguals were asked to translate words in each direction of translation, from Dutch to English (L1 to L2, forward translation) or from English to Dutch (L2 to L1, backward translation). The materials in the Kroll and Stewart study were presented one at a time but in lists that were either semantically categorized, with each member of a given list drawn from the same semantic category, or randomly mixed. The RHM predicts that the two directions of translation will differ in the degree to which they engage conceptual processing. If there is a strong lexical-level connection from L2 to L1, then translation in that direction should not necessarily require conceptual or semantic processing. In contrast, translation from L1 to L2 will be more likely to engage the meaning of the L1 word because the word to concept mappings are stronger for L1 than for L2. Kroll and Stewart found precisely this pattern in translation production. Dutch-English bilinguals were slower to translate from L1 to L2 when the words were presented in the context of semantically categorized lists, whereas the same manipulation had no effect on translation from L2 to L1. They argued that the insensitivity to the semantic manipulation for translation in the backward direction, from L2 to L1, suggested that translation was accomplished at a lexical level alone.

Behavioral Evidence for the Activation of the L1 Translation

In the time since the RHM appeared, there has been mixed support for the predictions of the model, with a debate that has been particularly focused on the issue of whether the L1 translation equivalent is activated when L2 words are processed (see Brysbaert & Duyck, 2010, and Kroll, Van Hell, Tokowicz, & Green, 2010, for a recent summary of the arguments on each side of this debate). Although performance has been examined across a range of comprehension and production tasks in both languages, there are three tasks that have provided the central evidence concerning the role of the L1 translation equivalent in L2 processing: translation production, translation recognition, and translation priming. We first review briefly the behavioral evidence using each of these tasks.

Translation production.

Potter et al. (1984) used a comparison of translation production and picture naming to test the predictions of the Word Association and Concept Mediation models. They argued that if the Word Association Model was correct, then direct access to the translation equivalent would effectively bypass conceptual processing, with the result that translation production would be predicted to be faster than picture naming, a task that necessarily requires conceptual processing to understand the meaning of the pictured object. They found that, if anything, picture naming was faster than translation, and for that reason rejected the Word Association Model in favor of the Concept Mediation Model. In the study by Kroll and Stewart (1994) reviewed above, translation production alone was performed to determine whether translation in each direction was sensitive to a semantic manipulation. They found different results depending on the direction of translation, with evidence for semantic or conceptual processing, only in the forward direction of translation, from L1 to L2. The results of these two studies led to different conclusions about translation performance but the data are actually not at odds with one another.

The critical comparison for Potter et al. (1984) was between picture naming in L2 and translation from L1 to L2. Kroll and Stewart also found that translation from L1 to L2 was conceptually mediated; only translation from L2 to L1, not the focus of the critical comparison in Potter et al., appeared to be lexically mediated.

The translation production studies that have produced mixed evidence for the RHM's predictions of lexically guided translation performance in the L2 to L1 direction have largely relied on the same research logic as used by Kroll and Stewart (1994). A semantic variable is introduced and manipulated in the context of translation in each of the two directions. The critical question is whether both directions of translation are equally sensitive to the semantic manipulation. If so, the result would suggest that both directions are processed conceptually, contrary to the idea that the translation equivalent in L1 is activated directly when the L2 word is processed. The results of these past studies are reviewed elsewhere (e.g., Kroll & Tokowicz, 2005; Kroll et al., 2010), but in brief, they show that manipulations of variables such as word concreteness or imageability (e.g., De Groot, Dannenburg, & Van Hell, 1994), semantic distance (e.g., Duyck & Brysbaert, 2004), and sensitivity to priming by a semantically related picture (e.g., La Heij, Hooglander, Kerling, & Van der Velden, 1996) affect translation in both directions. In some respects, finding that direct activation of the translation equivalent is not present is not terribly surprising if one considers that most of these studies have examined the performance of relatively proficient bilinguals. The RHM initially proposed that the reliance on the L1 translation equivalent in processing the L2 was a strategy that was adopted during early stages of L2 learning; once the ability to process L2 conceptually is in place, the logical need for the L1 translation should be reduced. [1] A more critical test of the role of the translation equivalent is to examine performance developmentally, as learners begin to acquire greater proficiency in using the L2. Because production tasks are notoriously difficult for learners, it is important to have a measure that is comparable for learners at different levels of L2 skill. De Groot (1992) developed a translation recognition task that has been used to examine this issue.

Translation recognition.

In translation recognition, a word in one of the L2 learner's or bilingual's languages is followed by a word in the other language and the task is to decide whether the second word is the correct translation of the first word. Talamas, Kroll, and Dufour (1999) developed a variant of the translation recognition task to index sensitivity to the form of the L1 translation equivalent. On half of the trials, the word pairs were not translations but words that were related in form or meaning to the correct translations. For example, some pairs resembled the correct translation in form (e.g., in Spanish and English the pair *hambre-man* would require a "no" response because *hambre* means hunger but resembles the correct translation pair *hombre-man*) whereas other pairs were related in meaning (e.g., *mujer-man* would also require a "no" response because *mujer* means woman). The time to reject these related word pairs as not correct translations was compared to the time to reject word pairs that were completely unrelated to each other. Talamas et al. (1999) found that sensitivity to these different types of foils was a function of proficiency. Less proficient learners were more likely than more proficient learners to be fooled by words

[1] A question of interest is why the relatively proficient Dutch-English bilinguals tested by Kroll and Stewart (1994) produced asymmetric translation performance given that they were at a similarly high level of proficiency as the bilinguals in the studies that have reported similar conceptual processing in both directions of translation. The reason may be related to the inclusion of relatively low frequency words in the Kroll and Stewart study (and see De Groot, 1993, for a discussion of word type effects in translation).

that resembled the form of the translation equivalent. The reverse was true for the semantically related pairs, with greater interference reported for more than for less proficient learners.

Although subsequent studies have produced a mixture of evidence regarding the relation between proficiency and semantic interference, for present purposes, the important finding is that differential sensitivity to the form of the translation equivalent has been reported for less and more proficient learners (e.g., Ferré, Sánchez-Casas, & Guasch, 2006; Sunderman & Kroll, 2006). The result was initially interpreted as support for the RHM in that the hypothesized reliance on the L1 translation appears to be stronger early in L2 learning than later when the ability to directly understand the meaning of L2 words has already developed. As we will see in the discussion of more recent evidence on this approach using ERPs, the pattern of findings is more complicated than the initial behavioral data suggested, with evidence that even relatively proficient bilinguals may activate the translation equivalent in some processing contexts.

Translation priming.

A third task that has provided important evidence on the availability of the translation equivalent in L2 processing is translation priming. A number of variations of the priming task have been used. A prime word is presented briefly at a duration at which it can be seen clearly or at a very brief duration with a masking stimulus so that the individual is not even aware that a word has been presented. The prime word is then followed at some interval by a target word and typically the task is to either make a lexical decision about the target word (i.e., is the letter string a real word?) or to make a semantic decision (e.g., is the target word a type of animal?). A number of parameters can be manipulated in priming paradigms that potentially affect the degree to which the task indexes automatic processing or deliberate expectations (e.g., see Altarriba & Basnight-Brown, 2007, for a review of recent methodological considerations in these paradigms). For the purpose of the present discussion, a critical observation is that when the prime is masked, there is also no information explicitly available to the participant concerning the language of the prime. A concern that has been voiced about bilingual studies is that there may be effects of expectations (e.g., Grosjean, 2001; Wu & Thierry, 2010b). In the translation production and recognition tasks reviewed above, the participant is aware that both languages are required to be engaged. If the reason that activation of the translation has been observed in the studies using these tasks is that participants are aware of the requirement to use the other language, then in a masked translation priming task it may be possible to process the target words in one language alone, without the influence of the other language. As we will see in the priming studies to be discussed and with a great deal of converging evidence from other bilingual paradigms (e.g., Van Hell & Dijkstra, 2002), the results of many priming studies now show that there is priming across the bilingual's two languages even when the prime itself is not visible and even when the two languages are structurally distinct, for example, in using different written scripts (e.g., Gollan, Forster, & Frost, 1997; Jiang, 1999).

At issue theoretically is whether there is an asymmetry in the direction of translation priming. If the RHM is correct, then more priming might be predicted from L2 to L1 than from L1 to L2, assuming that there is a direct translation-to-translation link that can be activated. In fact, past translation priming studies have reported every possible outcome, with more priming from L1 to L2, equal priming in both directions, and more priming from L2 to L1, depending on the task conditions. Duñabeitia, Dimitropoulou, Uribe-Etxebarria, Laka, and Carreiras (2010) reviewed the past translation priming literature and noted that studies that used lexical decision as the target task have typically reported asymmetrical effects in the two translation directions (e.g., De Groot & Nas, 1991; Dimitropoulou, Duñabeitia, & Carreiras, 2011; Finkbeiner, Forster, Nicol, & Nakamura, 2004; Gollan et al., 1997; Grainger & Frenk-Mestre, 1998; Jiang, 1999; Jiang & Forster, 2001; Kim & Davis, 2003; Schoonbaert, Duyck, Brysbaert, & Hartsuiker, 2009; Voga & Grainger, 2007; Williams, 1994; but see Duyck & Warlop, 2009). Duñabeitia et al. (2010) also noted that priming studies that have used semantic categorization tasks have been more likely to observe symmetry across the two directions (e.g., Finkbeiner et al., 2004; Grainger & Frenk-Mestre, 1998; Jiang & Forster, 2001).

Observations of symmetry or asymmetry within behavioral translation priming studies may not themselves be sufficient to adjudicate between alternative theoretical positions regarding the mapping of form to meaning in bilingual memory. For one thing, like the translation production studies reviewed above, performance by individuals who are beyond early stages of learning the L2 and are able to access meaning directly for L2 words might be expected to reveal more symmetric patterns of performance. More critically, the timecourse of processing words in the two languages may be critical. For all L2 learners and for most bilinguals, there is one language that is more dominant than the other. Often it is the native language, but when individuals have been immersed in the L2 for a long period of time, the L2 may become the dominant language (e.g., Heredia, 1997). If processing in the more dominant language is faster than in the less dominant language, then at a fixed duration, there may be more opportunities for the faster language to prime the slower language than the reverse. The likely differences in the timecourse of processing for the two languages therefore complicate the interpretation of asymmetries in priming. It may not be that the two languages map word forms to meaning in different ways but that they do so over different time frames. Differences in the timecourse of processing may also interact with the type of processing, making it more or less likely that the weaker of the two languages will access its respective meaning. As we discuss in the section that follows, an advantage of using ERP methods is that it provides a continuous record of the earliest stages of processing.

A critical study by Thierry and Wu (2007).

Before we discuss in detail the logic of using ERP methods, we describe the results of a study by Thierry and Wu (2007) that reported data that challenged previous interpretations regarding the activation of the translation equivalent by relatively proficient bilinguals. Like the translation priming studies, Thierry and Wu used a method that did not explicitly require the use of the nontarget language. In their study, highly proficient Chinese-English bilinguals living in the UK, so immersed in their L2, English, performed a semantic relatedness task. Two words were presented in English and their task was to decide whether the two words were semantically related to one another. Crucially, no Chinese was present. Unbeknownst to the participants, the pairs of English words sometimes had translations in Chinese that shared characters. The presence of shared characters in Chinese, however, was independent of whether the word pair in English was semantically related or not. There were both semantically related and semantically unrelated word pairs in English that contained shared Chinese characters. Thierry and Wu reasoned that if these Chinese-English bilinguals were able to function in English without activating the Chinese translations of the English words, then the presence of the shared Chinese characters in the Chinese translation should have no affect on their performance. They found that there was evidence in the ERP data that the presence of shared characters in the translation modulated the N400 (see next section for detailed information on the N400 and other ERP components) although the bilinguals were unaware of the Chinese translation. A comparison group of monolingual English speakers showed no effects when these shared characters were present. Thierry and Wu concluded that even relatively proficient bilinguals automatically and unconsciously activate the L1 translation equivalents ~~implicitly~~ when they process the L2. A later study (Wu & Thierry, 2010a) has shown that it is phonological rather than orthographic information about the L1 translation that is activated.

A recent study by Morford, Wilkinson, Villwock, Piñar, and Kroll (2011), using a behavioral version of the semantic relatedness task, reported a similar result for a group of deaf readers for whom American Sign Language (ASL) is the L1. The time to judge the semantic relatedness of word pairs in English was affected by whether the translation of the English words in ASL contained similar form elements. The result suggests that deaf readers activate sign translations even when they are reading in English alone and not explicitly required to use ASL. The findings held for highly proficient deaf readers demonstrating that the co-activation of sign was not due to lack of skill in reading English.

The results of both the Thierry and Wu (2007) and Morford et al. (2011) studies create a problem for the debate outlined above concerning the way in which bilinguals and second language learners map word forms to meaning. If the RHM is correct, then only individuals at a relatively early stage of acquiring the L2 should reveal a dependence on the L1 translation equivalent. In both the Thierry and Wu and Morford et al. studies, highly proficient bilingual readers revealed activation of the L1 translation equivalent when reading in the L2. These findings thus fail to support the developmental assumption of the RHM that learners access the L1 translation to facilitate understanding the meaning of the L2 word but that once they achieve sufficient proficiency in L2, they can access that meaning directly.

Many previous studies have shown that the process of accessing meaning can occur relatively early in L2 learning and indeed, that observation has been a focus in the debate over the RHM (e.g., Dufour & Kroll, 1995, and see Kroll et al., 2010, for a discussion of these findings). But the Thierry and Wu (2007) and Morford et al. (2011) results suggest that the L1 translation is not simply used as a means to transfer knowledge from L1 to L2 during the earliest stages of L2 acquisition. Instead, it appears to become active even once individuals are able to understand the meanings of L2 words directly. In the theoretical debate surrounding the RHM, those arguing that the predictions of the RHM failed to be supported have relied on the evidence for direct meaning access for L2 words as showing that it is not necessary to activate the L1 translation when processing the L2 (see Brysbaert & Duyck, 2010, for a summary of these arguments). The Thierry and Wu and Morford et al. studies provide compelling evidence for the activation of the L1 translation even among highly proficient bilinguals and even among bilinguals who have been immersed in an L2 environment for a long period of time.

In the remainder of this chapter, we first briefly discuss the basic principles of EEG/ERPs in language research. We then focus on how ERP methods can be used to resolve this apparent puzzle about the role of the L1 translation in L2 processing, and how L2 learners and bilinguals map word form to meaning. As we will see, the timecourse of processing, that may differ for the bilingual's two languages and in distinct ways across different processing tasks, may provide a key to allow us to begin to understand these apparent contradictions within the behavioral literature.

Basic Principles of EEG/ERPs in Language Research

Electrodes placed in key positions on the scalp can measure variations in electrical activity produced by large populations of brain cells. The recording of voltage variations over time is called the Electroencephalogram (EEG). Event-Related brain Potentials (ERPs) are derived from the EEG through a filtering process, and reflect regularities in electrical brain activity that are time-locked to an external event, like the presentation of a word (see, e.g., Handy 2005; Luck

2005, for excellent introductions to ERP recordings and analyses). Small voltage changes associated with, for example, reading a word are time-locked to the onset of the presentation of the word. These voltage changes make up the ERP signal. ERPs thus provide an on-line, millisecond-by-millisecond record of the brain's electrical activity during language processing. ERPs therefore can be used to index ongoing language-related perceptual and cognitive processes as they unfold over time.

A typical ERP signal consists of a series of positive and negative peaks (termed *components*) related to stimulus processing. ERP components are characterized by polarity, latency, amplitude, topographic scalp distribution, and a functional description of the cognitive processes they are assumed to index. An ERP component has either a positive polarity (positive-going wave, labeled by P), or a negative polarity (negative-going wave, labeled by N). Latency reflects the timecourse of the ERP signal and entails onset latency (the time at which a component begins), rise time (the time it takes to go from a low value to a high value), peak latency (the time at which a component reaches its peak amplitude), and duration (the length of the component). Components are often labeled according to their polarity and peak amplitude latency (e.g., N400 is a negative-going wave that reaches its peak amplitude around 400 ms after stimulus onset; see Figure 2). The relative peak amplitude of a component is assumed to reflect the degree of engagement of the associated cognitive processes. For example, the amplitude of the N400 decreases as the semantic relation between a word and the sentence in which it is embedded increases (e.g., Kutas & Federmeier, 2000). ERP components further have a characteristic topographical scalp distribution. Finally, components are functionally described in terms of the experimental manipulation to which a component is sensitive and the cognitive process(es) the component is assumed to reflect.

Insert Figure 2 about here

Components that have been identified as electrophysiological markers of the cognitive processes underlying word translation are the P200, N250, N400, and Late Positivity Complex (LPC). As we will see below, different variants of translation tasks (i.e., translation priming and translation recognition) elicit different components, and not all studies observe the same components.

The P200 is a positive-going wave in the 150 – 275 ms latency range that peaks around 200 to 250 ms after stimulus onset, and often coincides with the onset of the N400. It is distributed mainly over central-frontal and parietal-occipital electrode sites. The functional significance of the P200 is not yet completely understood, but evidence in language research (mostly priming studies) indicates that the P200 may reflect neural processes that occur when a visual input is compared with an expected word (e.g., Federmeier, Mai, & Kutas, 2005).

The N250 is a negative-going waveform in the 150-250 ms latency range that is sensitive to form-level processing (e.g., Holcomb & Grainger, 2006), and has been observed mainly in masked priming studies. The N250 is interpreted to index the mapping of sub-lexical form to orthographic representations. Adapting this idea to translation priming, this leads to two options. First, the presentation of a word in one language could rapidly activate its translation in the other language via direct lexical links. Alternatively, translation priming effects in the N250 may reflect feedback from semantic representations activated by the prime that influence form-level representations during target word processing.

The N400 is a large-amplitude negative-going wave in the 300-500 ms latency range, and peaks around 400 ms after stimulus onset. It is usually largest over central and parietal electrode sites. The N400 indexes the processing of semantic information, for example, relating the meaning of a word to the preceding linguistic context (e.g., Kutas & Federmeier 2000; Kutas & Hillyard 1980; Lau, Phillips, & Poeppel, 2008). It is enhanced, for example, when there is a semantic incongruency (e.g., Kutas & Hillyard 1980) or when words are difficult to integrate into a given linguistic context (e.g., Van Petten, Coulson, Rubin, Plante, & Parks 1999).

The LPC is a late positive-going wave that appears slightly after the N400 time window and extends for several hundred milliseconds. It typically has a broad posterior scalp distribution and, like the N400, is largest over centro-parietal scalp regions. The LPC is believed to reflect sentence-level integration (e.g., Kaan, Harris, Gibson, & Holcomb, 2000) or re-analysis (e.g., Friederici, 1995), a reconfiguration of stimulus-response mapping (e.g., Moreno, Rodriquez-Fornells, & Laine, 2008), and memory retrieval processes (e.g., Paller & Kutas, 1992).

One thing to note is that the typical latency and topographic characteristics of ERP components are based on adult speakers who perform a language task in their native language. In bilinguals who process language materials in their L2, slight variations in latency and topographic scalp distribution have been observed. For example, the onset of components, in particular later components like the N400, can be delayed in bilinguals when they are processing in their L2 (e.g., Arda, Donald, Meuter, Muldrew, & Luce, 1990; Moreno & Kutas, 2005; Van Hell & Tokowicz, 2010). A delayed onset is consistent with the idea that for unbalanced bilinguals who are more proficient in their L2 than in L1, processing in L2 is slowed down.

ERP Evidence on Translation in Bilinguals

In the next two sections, we will review ERP studies that used two variants of the translation task: translation priming and translation recognition.

ERP Translation Priming Studies

A paradigm that recently became increasingly popular in the ERP literature on translation is translation priming. In a typical translation priming study, bilinguals are presented with a target word (e.g., house) that is preceded by a prime in the same language (house – house), its translation (*casa* – house) or an unrelated word (skirt – house or *falda* - house). The primes and targets are typically noncognate words and presented in the bilingual's two languages, rendering L1-L1 and L2-L2 repetition priming conditions and L1-L2 and L2-L1 translation priming conditions. In the translation priming analysis, the ERP waveform of the target preceded by the translation prime is compared with the waveform of the target preceded by the unrelated prime. A translation priming effect is obtained when the ERP waveform in a particular time window (e.g., the N250 or N400) is more negative-going (or more positive-going in case of positive polarity) for targets preceded by unrelated primes than for targets preceded by their translation.

Alvarez, Holcomb, and Grainger (2003) presented native English speakers who were beginning or intermediate learners of Spanish with mixed lists of noncognate L1 and L2 words. To ensure semantic processing, they were instructed to read each word and press a button when a word referred to a body part (on 10% of the trials). The critical words were preceded on the previous trial by the same word (e.g., house – house; within-language repetition priming trials), their translations (e.g., *casa* – house; translation priming trials) or an unrelated word. Repetition priming trials were either L1-L1 or L2-L2. In the translation priming trials, the prime-target trials were either L1-L2, or L2-L1. The results showed that the amplitude of the N400 was modulated by translation priming, although the reduction in N400 amplitude was smaller in translation priming than in repetition priming. Importantly, the L2-L1 translation priming effects were larger in the 300-500 ms window (the typical N400 component), and declined in the subsequent 500-700 ms and 700-1000 ms windows. In contrast, the L1-L2 translation priming effects were small in the N400 time window, and tended to become stronger in the later phase of the LPC window (700-1000 ms). This indicates that translation priming from L1 to L2 has a later timecourse than translation priming from L2 to L1, which is in line with the RHM. The RHM states that translation priming from L2 to L1 is mostly lexically driven, and translation priming from L1 to L2 is mostly semantically driven. Presentation of an L2 prime automatically activates its L1 translation via the lexical-level connection, and because the L2-L1 lexical link is stronger than the L1-L2 lexical link, L2 words activate their L1 translations more rapidly, and more strongly. Indeed, the L2-L1 translation priming effect emerged earlier, and was larger, than the L1-L2 translation priming effect. The L1-L2 translation priming effect emerged in the later time windows, which may reflect the longer timecourse of activating semantic representations.

The participants in the Alvarez et al. (2003) study were native English speakers who were enrolled in beginning to intermediate courses in Spanish at a university. Their low proficiency in L2 and the developing L2 word form to concept mappings may underlie the translation priming asymmetry, and the delayed timecourse of L1-L2 versus L2-L1 translation priming. As predicted by the RHM, an increased L2 proficiency level should reflect more symmetrical patterns of L1-L2 and L2-L1 translation priming. Using the same within-language and between-language repetition paradigm as Alvarez et al. (2003), Geyer, Holcomb, Midgley, and Grainger (2011) examined highly proficient Russian-English bilinguals who emigrated to the US between ages 7-16, and were thus immersed in their L2. Geyer et al. indeed observed symmetrical effects for L1-L2 and L2-L1 translation priming, in the 300-500 ms and 500-700 ms windows. A direct comparison of the L2-L1 translation priming patterns of the lower proficient English-Spanish bilinguals in Alvarez et al. (2003) and the high proficient Russian-English bilinguals in Geyer et al. (2011) showed that the translation priming effects emerged later in the high proficient bilinguals than in the low proficient bilinguals. This suggests that an increase in L2 proficiency co-occurs with a decrease in the automaticity with which L2 words activate their L1 translation via direct lexical links, possibly because the direct lexical link becomes weaker with increased proficiency, and/or the L2 word form-to-concept link becomes stronger and more symmetrical to the L1 word form-to-concept link. Alternatively, the bilinguals tested by Geyer et al., who were immersed in their L2 environment and tested in an L2 context, may have inhibited their L1. The context in which these immersed bilinguals were tested may have produced a more inhibitory pattern for L1, in contrast to L2 speakers tested in an L1 environment (as, e.g., in Alvarez et al., 2003).

The large majority of studies in the emergent literature on neural correlates of translation priming presented words visually. An exception is the auditory word repetition and translation priming study by Phillips, Klein, Mercier, and De Boysson (2006). They presented fairly fluent English-French bilinguals quintets of words, via earphones. In the critical conditions, the first four words in each quintet were repetitions of the same word in L1 (e.g., bed, bed, bed, bed) or L2 (*jupe, jupe, jupe, jupe*), followed by a fifth word that was another repetition (e.g., bed), its translation (*lit*), or an unrelated word in the same (sky) or the other language (*ciel*). ERP responses to the fifth word were compared with the ERP responses to the first repetition of the word (word 2, at which the N400 was most attenuated). The L1-L2 translation condition (bed-*lit*) elicited a phonological mismatch negativity (PMN) in the 200-250 ms epoch followed by an N400 in the 350-550 ms epoch and a late posterior positivity between 600-800 ms. The L2-L1 translation condition (*jupe*-skirt) also elicited a PMN and a late posterior positivity in the 500-600 ms time window, so with an earlier onset than in L1-L2 translation. Notably, in contrast to the clear N400 in L1-L2 translation, no N400 was observed in L2-L1 translation. Finally, both the L1-L1 and L2-L2 repetition conditions elicited a PMN and N400, with the N400 appearing a bit later in L2-L2 repetition than in L1-L1 repetition.

A complicating factor in the interpretation of the translation asymmetry observed by Phillips et al. (2006) is that the repeated presentation of the L1 or L2 words, and the 500 ms interval in between presentation of two consecutive words, may have induced translation strategies in the bilinguals long before the critical fifth word, the actual translation, was presented. Likewise, in the translation priming studies of Alvarez et al. (2003) and Geyer et al. (2011), the time that elapsed between presentation of the prime and the target (stimulus-onset asynchrony, SOA) was quite long: 2700 ms in Alvarez et al. and 3350 ms in Geyer et al. Because the primes were clearly visible and the SOAs were long, the translation priming effects may have been driven by an overt translation strategy (cf. Altarriba & Basnight-Brown, 2007). For example, when participants consciously translate the L2 prime into L1 prior to the presentation of the L1, the ERP measurements actually reflect L1-L1 repetition priming rather than translation priming. Second, it is difficult to tease apart whether the translation priming effects are driven by word-form factors or semantic factors.

A technique in which the prime is presented very briefly (e.g., 50 ms) and masked (e.g., by hashes) prevents overt translation of the prime. Moreover, as proposed by Holcomb and Grainger (2006), masking the prime and using ERPs enables a more precise tracking of the timecourse of component lexical processes (earlier effects) and semantic processes (later effects) in priming. More specifically, Holcomb and Grainger (2006) argue that the N250 reflects early lexical processes in which prelexical orthographic representations are mapped onto orthographic representations. The N400 indexes semantic integration (Kutas & Hillyard, 1980) and a form-meaning interface in which lexical forms are mapped onto their semantic representations (Holcomb & Grainger, 2006), so a modulation of the N400 would signify the activation of semantic codes and word form to concept mappings. Applying this logic to the RHM, L2-L1 translation priming should be reflected in a modulation of the N250, at least in less proficient bilinguals whose L2 to L1 lexical links are strong and who are still developing their L2 word form to concept link. L1-L2 translation priming, on the other hand, should engage that activation of semantic information in both low and high proficient bilinguals, which would be reflected in a modulation of the N400.[2]

Using the masked translation priming technique with an SOA of 67 ms, Midgley, Holcomb, and Grainger (2009) presented fairly proficient French-English bilinguals with a target word in L1 or in L2, preceded by the same word (repetition priming), its translation

[2] To a certain extent, each of the components may reflect a combination of form and semantic influences, but it can be expected that lexical-level effects will be greater on the N250, and semantic-level effects will be greater on the N400.

(translation priming), or an unrelated prime. Participants were instructed to rapidly press a button when a word referred to an animal. Both L1-L2 and L2-L1 translation priming produced an N400 effect, although the N400 in L2-L1 translation priming was not typical (negative going at posterior sites, but reversed positive going at frontal sites). Midgley et al. (2009) also observed a modulation of the N250 in L1-L2 translation priming, but not in L2-L1 translation priming.[3] As argued by the authors, this may suggest a semantic influence early in processing in L1-L2 translation priming that was reflected in the N250 component and peaked around 300 ms post-target onset. The absence of an L2-L1 translation priming effect in the N250 is puzzling, and differs from the L2-L1 translation priming observed in the 300-500 ms windows in the unmasked priming studies by Alvarez et al. (2003) and Geyer et al. (2011). A possible account is that the bilinguals, all late learners who were less proficient in L2 than in L1, needed more time to fully process the briefly presented primes in their L2. The fact that L2-L1 translation priming effects were observed in the later N400 time window confirms that the bilinguals were slower and less efficient in processing L2 primes.

Following this line of argumentation, Midgley et al. (2009) predicted that with a longer L2 prime duration (and a longer SOA), L2-L1 translation priming effects should emerge in the N250 time window. This prediction was tested by Schoonbaert, Holcomb,

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[3] Chauncey, Grainger, and Holcomb (2008) used a similar masked priming procedure as Midgley et al. (2009), with a prime duration of 50 ms and 100 ms. The study was framed as a language switching study, ERPs were time-locked to the prime (rather than to the target as in Midgley et al.), and the language-switched (translation) trials were compared with non-switched (within-language repetition) trials (rather than to unrelated trials as in Midgley et al.). French-English bilinguals, who were moderately proficient in English, showed a language-switch related modulation in the N250 in the L1-L2 direction, but not in the L2-L1 direction, both with 50 ms and 100 ms prime duration, a pattern that parallels Midgley et al.'s translation priming findings. In the N400 region, switching effects were found for both L1-L2 and L2-L1 switching directions, in both prime duration conditions.

Grainger, and Hartsuiker (2010) who presented English-French bilinguals who were fairly proficient in their L2 French with L1 targets preceded by their L2 translations or unrelated words, or vice versa. Participants were asked to perform a lexical decision on the targets (and filler pseudowords). The prime duration was 100 ms and the SOA was 120 ms (in contrast to the 50 ms and 67 ms durations used in Midgley et al., 2009). In the L2-L1 translation priming condition, a modulation of the N250 was observed, followed by an N400 effect (both in the 300-400 and 400-500 ms windows) and a post N400 effect in the 500-600 ms window. The ERP pattern in L1-L2 translation priming was largely comparable to that of L2-L1 translation priming. A combined analysis of both translation directions yielded a subtle asymmetry in the N250 in that the N250 effect was larger in the L2-L1 direction than vice versa. The analysis also showed a larger, and more sustained N400 effect (in the 400-500 ms and 500-600 ms windows) in L1-L2 translation priming than in L2-L1 translation priming, which is likely to be related to a slower processing of L2 words, and thus an N400 latency shift for these words.

Schoonbaert et al.'s (2010) study indicates that robust L2-L1 translation priming effects can be obtained in masked priming with a somewhat longer prime duration, allowing bilinguals who are less proficient in their L2 sufficient time to process the L2 word. The translation asymmetry observed in the N250 window, with larger N250 effects in L2-L1 translation, shows that the asymmetry observed in the unmasked priming studies can also be observed when the prime is masked. Assuming that the N250 reflects lexical-level processes (as suggested by Holcomb & Grainger, 2006), it demonstrates that L2 primes more rapidly activate their L1 translation than L1 primes activate their L2 translations. This corroborates the asymmetry in the strength of the lexical links between words in L2 and L1, with L2-L1 links being stronger than L1-L2 links, in less proficient bilinguals, as proposed by the RHM. In fact, the RHM predicts that the L2-L1 priming effects will be most pronounced in the N250 window, and the L1-L2 priming effects be most pronounced in the N400 window. This is exactly the pattern found by Schoonbaert et al. (2010) and supports Midgley et al.'s (2009) conjecture that unbalanced bilinguals need more time to process the prime for L2-L1 priming to occur.

The masked and unmasked translation priming studies discussed so far used noncognate translations to prevent form overlap between prime-target trials from driving the translation priming effects. These studies tested bilinguals whose two languages shared the same alphabetic script (e.g., French and English) or have a Cyrillic and Latin script (e.g., Russian and English). The most extreme case that enables a test of how primes are processed with minimal interference from target orthography is created by examining the performance of bilinguals whose two languages have a completely different script (e.g., Japanese characters and English letters). As argued by Hoshino, Midgley, Holcomb, and Grainger (2010), the magnitude of translation priming effects depends on how well orthographic, phonological, and semantic information extracted from the prime can be integrated with orthographic, phonological, and semantic information extracted from the target. When the prime and target have a different script, the co-activation of orthography will not only be minimal, but different scripts also provide a strong bottom-up cue as to which language the prime belongs to, which will further reduce co-activation of lexical information. Cross-script translation priming thus creates an ideal testing ground for studying early semantic influences in bilingual lexical processing. Hoshino et al. (2010) presented relatively proficient Japanese-English bilinguals, immersed in the US in an L2 English environment, target words in L1 Japanese or in L2 English, in blocked lists. The targets were preceded by a masked prime, presented for 50 ms (SOA 80 ms), that was either the repetition of the target (repetition priming), the translation of the target (translation priming) or an unrelated word. The bilinguals were instructed to read the words and press a button when they detected a word that referred to a body part (go/no-go semantic categorization). For L1-L2 translation priming, a significant N250 effect was obtained, followed by a significant N400 effect; at the anterior sites, there was also evidence of a very early effect in the 100-200 ms epoch. In contrast, no L2-L1 translation priming effect was observed in any of the time windows. Repetition priming effects were obtained for both L1 and L2 targets, in the N250 and N400 time windows. Hoshino et al. argued that it is unlikely that the L1-L2 translation priming effect reflected an automatic activation of the L2 translation of the L1 prime at the lexical level: This should have resulted in larger L2-L1 than L1-L2 priming effects, and the opposite pattern was obtained. Rather, they interpreted the L1-L2 translation priming effects in the N250 as signifying that L1 primes rapidly activate their semantic representations, and this activation feeds back and influences lexical-level representations of the L2 target. The L1 primes modulated ERP responses to L2 targets throughout the N250 and N400 time windows. The absence of translation priming effects from L2 to L1 may reflect the bilinguals' relatively slow processing of L2 prime words that were presented for 50 ms.

The masked translation studies discussed so far tested unbalanced, successive bilinguals who were less proficient in their L2 than in their L1, and who learned their L2 at school after the age of seven or older. This raises the question to what extent the previous findings are specific to unbalanced, successive bilinguals, or whether they also generalize to bilinguals with more balanced proficiency across the two languages? Previous behavioral studies on translation production suggest that unbalanced bilinguals who are strongly dominant in the L1 are likely to produce a translation asymmetry, with faster translation from L2 to L1 than from L1 to L2, whereas more proficient or balanced bilinguals are more likely to produce similar translation performance in the two directions (e.g., Kroll, Michael, Tokowicz, & Dufour, 2002).

To examine the consequence of balanced bilingualism for ERP performance on masked translation priming study, Duñabeitia, Dimitropoulou, Uribe-Etxebarria, Laka, and Carreiras (2010) tested highly proficient, simultaneous Basque-Spanish bilinguals, who were native speakers in each of the languages and had a balanced use of both languages on a daily basis. They were presented with Basque and Spanish words (in two different blocks), that were preceded by identical primes (e.g., *cuento – CUENTO*; [English translation: tale]), translation primes (*ipuin – CUENTO*), or unrelated primes in the same (*huelga – CUENTO*; [English translation *huelga*: strike]) or different (*antza - CUENTO*) language as the target. Primes were masked and presented for 50 ms, and participants were instructed to read the words and detect words (by pressing a button) that referred to animal names (go/no-go semantic categorization task). The proficient bilinguals' ERP data showed a significant N400 effect that was symmetrical for L1-L2 and L2-L1 translation. No translation priming effects were observed in the N250. The observed translation symmetry in the highly proficient Catalan-Spanish bilinguals replicates the symmetrical pattern observed in the highly proficient Russian-English bilinguals in Geyer et al.'s (2011) unmasked priming study. Together these findings suggest that in highly fluent bilinguals, the neural correlates of L2 form-to-concept mappings are symmetrical to those of L1-form-to-concept mappings.

ERP translation priming studies: wrap up.

One question this review of ERP translation priming studies raises pertains to the instructions participants received to assure they read the stimuli attentively. Some studies asked participants to perform a lexical decision on the target word (Geyer et al., 2011; Schoonbaert et al., 2010), whereas other studies asked participants to make a semantic categorization and decide whether or not the target word referred to a body part (Alvarez et al., 2003) or to an animal (Duñabeitia et al., 2010; Hoshino et al., 2010; Midgley et al., 2009). The lexical decision and semantic decision tasks make different demands on the activation of orthographic, phonological, and semantic knowledge. For example, semantic information will be more strongly involved in a semantic decision on the target word as compared to deciding whether a letter string is a word or not. In the behavioral literature, as discussed above, translation priming studies that used a semantic decision task tended to find symmetrical translation effects, whereas studies using a lexical decision task typically found asymmetrical translation effects. This suggests that semantic decision recruits both L1 word-to-concept mappings and L2 word-to-concept mappings, whereas lexical decision recruits mainly L1 word-to-concept mappings.

Can the translation priming studies using ERP methodology be interpreted along similar lines? Not really. The four studies using a semantic decision task observed quite different translation priming patterns. Duñabeitia et al. (2010) found symmetrical translation priming effects in the N400 in highly proficient Catalan-Spanish bilinguals, whereas Hoshino et al. (2010), testing fairly fluent Japanese-English bilinguals, observed L1-L2 translation priming effects in the N250 and N400 but found no effects in L2-L1 translation priming. Midgley et al. (2009) observed symmetrical translation priming in the N400, but only L1-L2 translation priming was observed in the N250. Finally, Alvarez et al. (2003), testing beginning-intermediate L1 English learners of L2 Spanish, observed both L1-L2 and L2-L1 priming effects, but L1-L2 translation priming had a later timecourse than L2-L1 translation priming. The two studies that asked participants to perform a lexical decision task observed symmetrical L1-L2 and L2-L1 translation priming effects in highly proficient Russian-English bilinguals (Geyer et al., 2011) and in fairly proficient English-French bilinguals (Schoonbaert et al., 2010), although the bilinguals in the latter study showed a larger N250 effect in the L2-L1 direction than vice versa, and a more sustained N400 effect in L1-L2 priming than in L2-L1 priming.

These variable ERP patterns reflect the large variability across electrophysiological studies on translation priming studies in terms of methodology (including masked versus unmasked presentation of the prime, prime duration, task instructions that emphasize semantics or word form codes, mixed versus blocked presentation of the L1 and L2 targets), and the participants (variations in L2 proficiency, age of first exposure to the L2, language learning history, L2 immersion). Such variation is not uncommon in the emergent literature of studies on bilingual processing using ERPs (see, e.g., review studies by Kotz, 2009; Moreno et al., 2008; Van Hell & Tokowicz, 2010; Van Hell & Witteman, 2009). It suggests that more systematic studies are needed, taking into account and possibly controlling for the factors outlined here, before we can draw any firm conclusions. It also shows that insights into the timecourse of translation priming obtained using ERPs add novel and important evidence to the reaction time and accuracy data obtained in behavioral translation priming studies.

One important factor that has been largely overlooked in both the behavioral and the ERP literature (but see Guasch, Sánchez-Casas, Ferré, & García-Albea, in press) pertains to the degree of meaning similarity of a word in one language and its translation. The implicit assumption in non-cognate translation priming studies is that the meanings of translation equivalents are similar, and that translation equivalents provide the closest possible semantic relation between two different word forms (see, e.g., Duñabeitia et al., 2010; Midgley et al., 2009). As argued by Duñabeitia et al. (2010), assuming that an N400 effect reflects how well orthographic, phonological, and semantics representations activated by the prime are integrated with orthographic, phonological, and semantics representations activated when reading (or hearing) the target, no differences are to be expected between repetition priming and translation priming. But is it legitimate to assume that the meanings of the target in one language and its translation prime are identical, as in the target and its repetition prime? Several behavioral (e.g., Degani, Prior, & Tokowicz, 2011; Laxén & Lavaur, 2010; Tokowicz, Kroll, De Groot, & Van Hell, 2002; Van Hell & De Groot, 1998a) and neuroimaging (Illes et al., 1999) studies suggest that the semantic representations of two translations do not always overlap completely, at least in bilinguals with different levels of proficiency in their two languages, or in certain word types. For example, Van Hell and De Groot (1998a) asked Dutch-English bilinguals to perform a word association task twice on the same list of words (nouns and verbs that varied in concreteness and cognate status), once in the language of the stimuli (within-language) and once in the other language (between-language). It appeared that the within- and between-language associations for concrete words and for cognates were more often translations of one another than those for abstract words and noncognates, and nouns evoked more translations than verbs. This suggests that lexical and conceptual representations may be more similar for some types of words (e.g., concrete cognate nouns like apple-*appel*) than for others (e.g., abstract noncognate nouns like truth-*waarheid*).

A recent behavioral translation and semantic priming study, in which the degree of semantic relatedness between prime-target pairs was manipulated, provides further evidence that semantic overlap affects priming (Guasch et al., in press). Guasch et al. presented highly proficient Catalan-Spanish bilinguals with prime-target pairs that were either translations (*ruc-burro* [donkey]), very closely related (*ruc-caballo* [horse]), closely related (*ruc-oso* [bear]), or unrelated. Primes and targets were presented in L1 and L2, and vice versa, and the bilinguals performed a lexical decision task or a semantic decision task on the target words. In both language directions, and in both tasks, the degree of semantic overlap modulated the magnitude of the priming effects: Priming effects were largest in the translation pairs, somewhat smaller in the closely semantically related pairs, and smallest in the semantically related pairs.

In their group of highly proficient bilinguals (they refer to these bilinguals as 'multiple L1' bilinguals), Duñabeitia et al. (2010) found that the N400 translation priming and repetition priming effects were basically identical, which indeed hints at complete semantic overlap of translations. However, other translation priming studies using less proficient L2 speakers typically observed smaller and less robust translation priming effects than repetition priming effects, even in case of L2-L2 repetition priming (Alvarez et al., 2003; Geyer et al., 2011; Hoshino et al., 2010). This suggests that the implicit assumption that within-language repetition priming is comparable to between-language translation priming in the recruitment of semantic information may not hold for bilinguals who are less proficient in L2 than in L1.

ERP Translation Recognition Studies

In the masked and unmasked translation priming studies, the bilinguals were instructed to read the words and to perform a lexical decision on the target, or to decide whether the target refers to a body part or to a living creature. They were never instructed to make a translation decision, or to even relate words from the two languages in a meaningful way. One could argue that the evidence emanating from the translation priming studies informs the component processes involved in word recognition, which is a first component of word translation, but does not capture all processes involved in word translation. Only a handful of electrophysiological studies have examined word translation under conditions in which bilinguals were instructed to make an explicit decision on whether an L1 and an L2 word are translations or not. In the first published ERP study on translation recognition, Vigil-Colet, Pérez-Ollé, and García-Albea (2000) studied highly proficient Catalan-Spanish and Spanish-Catalan bilinguals who performed a translation recognition task in which correct and incorrect translation pairs were presented in both L1-L2 and L2-L1 translation directions. The first word was presented for 500 ms, and after a random interval of 1000-2000 ms, the second word was presented for 500 ms. Vigil-Colet et al. found that the P300 – P600 complex was involved in translation recognition and concluded that these components may be viewed as indexes of stimulus relevance and activation in short-term memory.

Vigil-Collet et al. (2000) framed their study in the memory literature and focused on P300-P600 components that index short-term memory processes. This study remains largely silent on the specific ERP components, like the N400, that were studied in the later published translation priming studies. In a recent translation recognition study using ERPs, Palmer, Van Hooff, and Havelka (2010) focused more directly on lexical and semantic processing and the RHM. Palmer et al. hypothesized that the N400 effect should be larger in L2-L1 translation recognition than in L1-L2 translation recognition. They argued that when an L2 word precedes its L1 translation, the L2 word should rapidly activate the L1 word via the relatively strong L2-L1 lexical link, even before the L1 word is actually presented. If indeed the L1 word is the correct translation (in the correct translation trials), the pre-activation of the L1 word's lexical and semantic representations should facilitate the lexical-semantic integration process, which should reduce the N400 amplitude in response to the L1 word. However, if the L1 word is the incorrect translation, a large N400 inflection is predicted due to violation of expectancy. The resulting N400 effect (in which the correct and incorrect translation conditions are contrasted) should be large in L2-L1 translation. In the case of L1-L2 translation recognition, the L1 word does not rapidly activate its L2 translation because translation occurs via the slower conceptual links. When the L2 translation is presented, only the shared semantic representation has been pre-activated by the L1 word, which will lead to a reduced N400 amplitude in case the correct L2 translation is presented, but to a lesser extent than in L2-L1 translation. Presentation of the incorrect L2 translation will elicit an N400, but this N400 will be smaller than in L2-L1 translation because expectancy violation will be smaller. Therefore, the N400 effect in L1-L2 translation is predicted to be smaller than in L2-L1 translation.

Palmer et al. (2010) tested Spanish-English (Experiment 1) and English-Spanish (Experiment 2) bilinguals with a rather wide range of L2 proficiency levels and age-of-first exposure to L2; the Spanish-English bilinguals were immersed in their L2, and the English-Spanish bilinguals were immersed in their L1. They were presented with two words in L1 and L2 or vice versa, that were correct translations or not. Half of the words had low imageability ratings and half had high imageability ratings. The first word was presented for 500 ms, and after a blank screen of 300 ms the second word was presented, with a resulting SOA of 800 ms. In both groups of bilinguals, L2-L1 translation elicited a larger N400 effect than L1-L2 translation. In the L2 non-immersed bilinguals, but not in the L2 immersed bilinguals, a similar asymmetry was observed in the reaction time data such that L2-L1 translation was faster than L1-L2 translation. In the ERP data, concreteness did not affect the N400 (although concrete translations were recognized faster and more accurately in the behavioral data in the L2 immersed but not in the L2 non-immersed bilinguals) and concreteness did not modulate the translation asymmetry observed in the ERP data. The larger N400 effect in L2-L1 than in L1-L2 translation supports the asymmetry assumption in the RHM.

In the ERP evidence in the Vigil-Collet et al. (2000) and Palmer et al. (2010) studies, it is difficult to tease apart lexical and semantic factors involved in translation recognition. Two recent studies explored the neural correlates of lexical and semantic interference effects in translation recognition, employing the lexical and semantic distractor manipulation that has been successfully used in behavioral studies (e.g., Comesaña, Perea, Piñeiro, & Fraga, 2009; Ferré et al., 2006; Sunderman & Kroll, 2006; Talamas et al., 1999). Guo, Misra, Tam, and Kroll (under review) compared ERP and behavioral performance in a translation recognition task performed in the L2 to L1 direction with highly proficient Chinese-English bilinguals immersed in the L2 in the US. When the L1 word was not the correct translation, it was either related to the correct translation by sharing phonology with the translation, similar in meaning to the correct translation, or completely unrelated. In a first experiment, Guo et al. found evidence for sensitivity to both types of distractors in both the behavioral and the

ERP data. However, the timecourse of activation revealed by the ERP record distinguished responses to the distractors related in form to the translation from those that were semantically related to the translation. Early in processing, there was a P200 for the translation form distractors in contrast to the N400 that was observed for the semantically related distractors. For both types of distractors, there was an LPC effect from 500-700 ms that presumably reflected the mapping of stimulus processing onto a decision, although again the pattern was distinct for the two types of distractors.

At one level, the results of Guo et al. (under review) using the translation recognition paradigm replicated the main features of Thierry and Wu's (2007) results. Highly proficient Chinese-English bilinguals immersed in a predominantly English-speaking environment produced evidence that they activated the Chinese translation equivalent. However, the two studies, although using different paradigms, were also similar in another respect in that they both used relatively long SOAs between the presentation of the first and second words. In the Guo et al. study, the SOA was 750 ms and in the Thierry and Wu study the SOA ranged from 1000 ms – 1200 ms. Guo et al. reasoned that the long SOA may have allowed or encouraged access to the translation equivalent for these proficient bilinguals. In a second experiment, they replicated the same distractor conditions in the translation recognition task with a matched group of Chinese-English bilinguals but with the SOA between the L2 and L1 words reduced to 300 ms. Under these short SOA conditions, there was again evidence for a strong effect for the semantic distractors but a marked reduction in the sensitivity to the translation distractors. The pattern of results suggests that direct access to the L1 translation equivalent of the L2 word may depend on whether the task conditions provide sufficient time and opportunity to engage the translation (cf. Schoonbaert et al., 2010). The fact that sensitivity to the meaning of the L2 word is not affected by the timing to the same extent suggests that for highly proficient bilinguals, the translation of the L2 word may be activated once the meaning of the word has been accessed.

All studies discussed so far examined adult bilinguals or L2 learners. However, many bilinguals have learned their L2 during childhood, often in a classroom, but remarkably few experimental studies have examined the initial stages of developing L2 lexical-semantic knowledge in *child* classroom learners (but see Brenders, Van Hell, & Dijkstra, 2011; Brenders, Van Hell, & Dijkstra, under review; Comesaña et al., 2009; Poarch & Van Hell, accepted). Using the translation recognition paradigm, Brenders, Van Hell, and Dijkstra (under review) examined Dutch classroom learners of L2 English in fifth and sixth grade of elementary school (after 5 and 16 months of instruction, respectively) and adult proficient Dutch-English bilinguals. Following the critical manipulations in the Talamas et al. (1999) study, participants were presented with correct L2-L1 translation words (e.g., chair-stoel), semantic distractor words (chair-*kast* [closet]), word form distractor words (chair-*stoep* [sidewalk]), or unrelated control words (chair-*fiets* [bike]). The L2 word was presented for 350 ms, followed by a blank screen for 300 ms, after which the L1 word was presented for 350 ms. Participants were instructed to delay their 'yes' or 'no' response until a warning cue was presented (at variable time intervals to prevent contamination of the EEG by motor artifacts). The most important finding was that, for both beginning L2 learners and proficient bilinguals, the ERP analyses yielded an N400 effect for semantic distractor pairs relative to incorrect control pairs. Moreover, the N400 was less negative going for the word form distractors than for incorrect controls in the fifth grade beginning learners, but more negative going in the sixth grade beginning learners and proficient bilinguals. The reaction time and accuracy data, collected in a parallel behavioral experiment, mimicked the ERP data.

The RHM proposes a shift in translation from reliance on lexical links to reliance on conceptual links as L2 proficiency increases. The ERP and behavioral data of the beginning L2 learners tested by Brenders et al. (under review) suggest that already at an early stage in L2 learning, these classroom learners activate semantic information during the word recognition task. This finding adds to accumulating evidence that, under certain conditions, L2 learners in an early stage of L2 learning activate semantic information, and employ L2 word-to-concept mappings (cf. Kroll et al., 2010). One such condition appears to be the context in which L2 learning takes place, in particular the semantic richness of the L2 learning situation (cf., Trofimovich & McDonough, 2011). L2 English elementary school instruction methods used in Dutch schools typically teach novel words in semantically rich and meaningful contexts, using learning situations enriched by pictures and real-life situations. These are optimal conditions for fostering L2 word form to concept mappings. In contrast, adult beginning learners who learn their L2 at the university often learn L2 vocabulary by connecting the novel word to its translation. This word-word learning method boosts lexical-level links. The suggestion that conditions in which L2 words are learned affects the strength of L2 word form-to-concept mappings is corroborated by a recent study by Comesaña et al. (2009). They taught Spanish-speaking children (with no knowledge of Basque) L2 Basque words via either L2-picture association learning or L2-L1 word association learning, and later tested the children using a translation recognition task in which they presented semantically related or unrelated word pairs as the critical incorrect translation pairs. In L2-picture association learning, but not in L2-L1 word association learning, a significant semantic interference effect was observed, after just one vocabulary learning session. The observation of semantic effects in an early stage of L2 learning parallels Brenders et al.'s (under review) findings, and indicates that the use of pictures might have stimulated the development of L2 word-to-concept mappings. A recent neurocognitive L2 learning study showed that L2 word retrieval engaged different cortical structures depending on how these L2 words had been learned (via written L1 translations or in a context-rich real-life situation; Jeong,et al., 2010). Variations in learning strategy may thus have a profound influence on the neural underpinnings of lexical and conceptual links in second language learners and bilinguals.

ERP Evidence on Translation and the Revised Hierarchical Model: Concluding Remarks

Since the initial word translation studies were published in the 1980's and 1990's and the first models were proposed to capture the lexical and conceptual links engaged in word translation (i.e., the word association and concept mediation models, and their combination in the RHM), numerous behavioral and ERP studies have been published that together provide a wealth of insights into the codes that are engaged when translating words from one language to the other, and the timecourse of accessing form and meaning in two languages. The present review of behavioral and ERP studies indicates that the majority of evidence can be captured with the basic assumptions of the RHM, provided that two qualifications are made with respect to the original model proposed about 20 years ago (Kroll & Stewart, 1994).

First, a general pattern that emerges from the ERP studies reviewed in this chapter is that L2 to L1 lexical links tend to be stronger than L1 to L2 lexical links, in line with the original RHM. Unlike the initial proposal, however, the L2-L1 lexical links do not decay as L2 proficiency increases. Rather, not only beginning L2 learners but also relatively proficient bilinguals seem to employ this L2-L1 lexical level link, and activate the L1 equivalent when processing a word in the L2 (e.g., Alvarez et al., 2003; Geyer et al., 2011; Morford et al., 2011; Schoonbaert et al., 2010; Thierry & Wu, 2007), particularly in situations when L2 language processing is challenging. The current behavioral and ERP evidence also seriously challenges recent claims that lexical-level L2-L1 connections do not exist (Brysbaert & Duyck, 2010). Rather, the co-activation and translation of L2 words and their L1 equivalents appear to be a fundamental phenomenon in bilingual processing. The critical question is not so much whether the L1 equivalent is activated when reading or hearing words in the L2, but, rather, how the L1 is used at different stages of L2 learning and in different language processing contexts.

A second important component of the RHM pertains to L2 word form to concept mappings, and the conceptual links between L2 words and their meanings. In the initial 1994 version of the RHM, this link was assumed to develop with increased L2 proficiency. Behavioral evidence suggests that moderately proficient L2 learners can directly access L2 word meanings (Dufour & Kroll, 1995; see Kroll et al., 2010 for further discussion), but recent studies on child learners indicate that child beginning L2 learners activate L2 word meanings in a very early stage of L2 learning (Brenders et al., under review; Comesaña et al., 2009). This activation of L2 word meaning in this early stage of L2 learning seems to be boosted by the context-rich and meaningful L2 learning environment in which these children were embedded.

To conclude, the currently available ERP and behavioral evidence on how L2 learners and bilinguals exploit lexical and conceptual links indicates that a hallmark of proficient language use is the ability to fully exploit lexical and conceptual links depending on linguistic and contextual task demands, the difficulty of the language materials the bilingual perceives or produces, and the situational context of language learning and language use. The high end of bilingual processing may be a bilingual whose L1-L2 and L2-L1 processing is fully symmetrical, as in the Basque-Spanish bilinguals tested by Duñabeitia et al. (2010). Until this stage is reached, L2 learners' and less proficient bilinguals' processing may be characterized by asymmetries in L1-L2 and L2-L1 processing, along the lines reviewed in this chapter. Future research may delineate conditions that are associated with such asymmetries.

One such line of future research may explore the role of L2 immersion, and how component processes of translation differ for L2 learners and bilinguals immersed in an L2 environment (e.g., Geyer et al., 2011; Hoshino et al., 2010; Thierry & Wu, 2007) as compared to bilinguals who are tested in the L1 environment (e.g., e.g., Alvarez et al., 2003; Midgley et al., 2009; Schoonbaert et al., 2010). In the past decade, many studies have examined how L2 proficiency and Age of Acquisition (AoA) modulates L2 processing, but the influence of L2 immersion remained largely unexplored. As alluded to above, the surprising finding that L2-L1 translation priming effects emerged later in highly proficient Russian-English bilinguals (Geyer et al., 2011) than in lower proficient English-Spanish bilinguals (Alvarez et al., 2003) may be related to the fact that the highly proficient bilinguals may have inhibited their L1 while immersed in an L2 environment. A recent behavioral study by Linck, Kroll, and Sunderman (2009) indeed showed that translation recognition performance among L2 learners was modulated by conditions of language immersion. When English learners of Spanish at an intermediate level of proficiency had classroom L2 experience only, they produced significant behavioral interference in translation recognition for distractors that resembled the form of the translation and also for distractors that were semantically related. However, when English learners of Spanish at the same intermediate level were immersed in a study abroad program in Spain, the effect for the translation distractors was eliminated but the semantic effects were strong. Together with other evidence in that study, Linck et al. argued that the L1 appears to have been inhibited in the L2 immersion environment.

A final suggestion we make for future research is to explore the electrophysiological correlates of translation production. Behavioral studies on translation production opened the field, and led to important insights into the role of lexical and conceptual information in L1-L2 and L2-L1 translation (De Groot, 1992; De Groot et al., 1994; Kroll & Stewart, 1994; La Heij et al., 1996; Potter et al., 1984; Van Hell & De Groot, 1998b), but ERP evidence on the timecourse of component processes involved in translation production, and possible differences between L1-L2 vs. L2-L1 translation production, is currently lacking.

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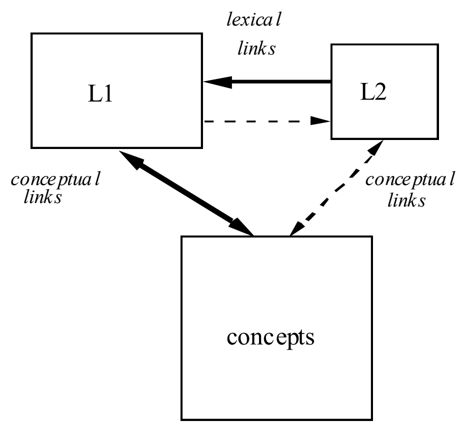
Figure Captions

Figure 1. The Revised Hierarchical Model (adapted from Kroll & Stewart, 1994).

Figure 2. An illustration of the N400 component in ERP waveforms.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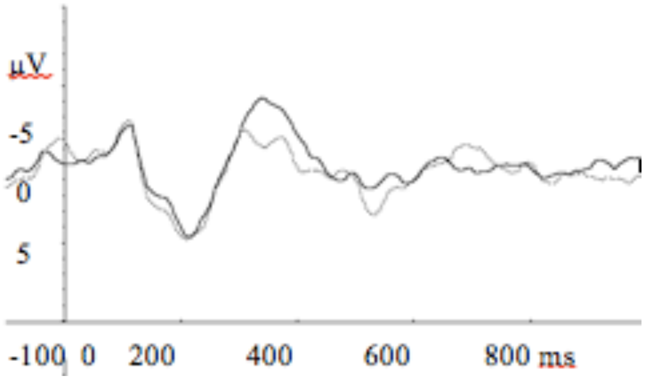
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