Bilingual visual word recognition in sentence context

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Abstract

The recognition that more of the world's speakers are bilingual than monolingual has led to a dramatic increase in research on bilingual language processing in the past decade, including research on visual word recognition. One of the central questions in bilingual word recognition studies is whether bilinguals can selectively turn off one language. A large body of evidence suggests that they can't: Bilinguals non-selectively activate both languages in parallel, even when they are attempting to read and speak in one language alone. If the bilingual's two languages are both active, how do bilinguals control their two languages and resolve the cross-language competition to allow fluent performance?

In this chapter we review research on the nature of cross-language activation during bilingual lexical access and how it is modified by the presence of a sentential context. We start with a review of evidence for language non-selectivity observed out of context. We then discuss recent research on three possible sources of constraint supplied through a sentence context: (1) language membership of words, (2) semantic information from top-down comprehension processes and (3) syntactic features of the sentence structure. Finally, we discuss implications for current models of bilingual lexical access as well as for monolingual models of sentence final context and suggest future directions for research.

Researchers in cognitive science have a long history of answering questions about the nature of mental processes through the examination of word recognition. For example, one of the most well-known connectionist models of human cognition (the Interactive Activation framework) is a model of word identification (McClelland & Rumelhart, 1988). Research on word recognition has demonstrated that lexical retrieval is a highly interactive process, characterized by parallel activation of competing representations before resolution to a single lexical entry (*see also chapters by, for example, Coltheart, Sibley & Kello, Forster, Balota et al., Grainger & Dufau, Halderman, Ashby, & Perfetti, Feldman & Weber, Volumes 1 and 2, this series*). However, models and theories of word identification focused exclusively on processing within a monolingual lexicon despite the fact that most of the world's population is bilingual. This began to change in the 1990's in which there was a sudden heightened interest in examining the nature of lexical co-activation across languages. The central question of interest was whether lexical activation proceeds selectively by language such that only competitors in the target language can be activated. The answer based on much evidence accrued throughout the 90's to today is a resounding "No"

Many studies using different variations of single word recognition paradigms such as lexical decision and naming have demonstrated that when bilinguals recognize words, there is parallel co-activation of lexical entries from both languages. To test for cross-language lexical co-activation the common strategy has been to manipulate the orthographic, phonological or semantic similarity of words from the two languages of the bilinguals (and in some cases the three languages of trilinguals) being tested. The most frequently used comparison has been that between cognates, i.e. words that share a high degree of meaning and form overlap (e.g., the Spanish-English translations 'piano-piano' or 'palace-palacio') and noncognate control words. If

cognates are processed differently (i.e.,showing different reaction times and/or accuracy rates) than noncognates (matched on lexical factors including frequency, length, and orthographic neighbors), it is assumed that representations of the cognate from both languages were simultaneously co-activated prior to the completion of lexical access, thereby altering the time-course and/or ease of access.. The majority of studies have presented cognates and noncognates in the bilinguals' L2, and have found facilitated performance (faster reaction times and/or greater accuracy) than noncognate controls (e.g., Blumenfeld & Marian, 2007; Caramazza & Brones, 1979; Cristoffanini, Kirsner, & Milech, 1986; Costa, Caramazza, & Sebastián-Gallés, 2000; De Groot & Nas, 1991; Dijkstra, Grainger, & Van Heuven, 1999; Dijkstra, Van Jaarsveld, & Ten Brinke, 1998; Lalor & Kirsner, 2001; Lemhöfer, Dijkstra, & Michel, 2004; Sánchez-Casas, García-Albea, & Davis, 1992; Schwartz, Kroll, & Diaz, 2007). Cognate facilitation effects have been found when the words were presented in the first, and dominant, language, L1 as well (Van Assche, Duyck, Hartsuiker, & Diependaele, 2009; Van Hell & Dijkstra, 2002). For example, Van Hell and Dijkstra (2002) presented Dutch-English-French trilinguals (with relatively high proficiency in both English-L2 and French-L3) with L1 Dutch words that were either cognates with English, cognates with French, or noncognate controls in a Dutch lexical decision task. The trilinguals' performance showed a cognate facilitation effect for both L1 Dutch-L2 English cognates and for L1 Dutch-L3 French cognates. This study demonstrates that cognate facilitation effects are not restricted to L2 processing (in which a weaker L2 is affected by the stronger L1), but can also occur in L1 processing (even a stronger L1 can be affected by a weaker L2). Cognate facilitation is one of the most robust effects of cross-language non-selectivity in lexical processing and has been observed across a wide variety of paradigms and languages, even languages that differ in script like Hebrew-English (Gollan, Forster, & Frost, 1997), Greek-

English (Dimitropoulou, Duñabeitia, & Carreiras, in press; Voga & Grainger, 2007), Korean-English (Kim & Davis, 2003), or Japanese-English (Hoshino & Kroll, 2008).

Effects of non-selectivity in lexical processing have also been observed for words in two languages that do not share semantics but do share either orthography (interlingual homographs such as the Dutch word 'angel' meaning 'stinger' in Dutch) or phonology (interlingual homophones such as the Dutch word 'kou' pronounced as 'cow' but meaning 'cold'). Many studies found that lexical access of interlingual homographs and homophones differs from that of matched control words, and can be either facilitated or inhibited depending on factors like the composition of the stimulus list or specific task demands (Brenders, Van Hell, & Dijkstra, 2011; Brysbaert, Van Dyck, & Van de Poel, 1999; de Bruijn, Dijkstra, Chwilla, & Schriefers, 2001; De Groot, Delmaar, & Lupker, 2000; Dijkstra et al., 1999; Dijkstra, De Bruijn, Schriefers, & Brinke, 2000; Van Heuven, Dijkstra, & Grainger, 1998; Von Studnitz & Green, 2002).

It should be noted that the effects observed with interlingual homographs and homophones have been far less consistent than those observed for cognates, suggesting a critical role of shared semantics in augmenting and/or sustaining cross-language activation. For example, one study showed that interlingual homographs may be recognized slower than or as fast as monolingual control words depending on task requirements and language intermixing (Dijkstra et al., 1998). Dutch-English bilinguals were presented with cognates and interlingual homographs in an L2 lexical decision task. While recognition performance was facilitated for cognate items, no effects on performance were observed for interlingual homographs. In a second experiment, Dutch-English bilinguals again performed an English lexical decision task on homographs, but the stimulus set included in addition to nonwords, Dutch words which required a "no" response. In this case, recognition of the interlingual homographs showed strong

homograph inhibition effects, which were dependent on the relative frequency difference of the two readings of the homograph in the two languages.

For effects of language non-selectivity to be observed in word recognition performance the words in the bilinguals' two languages do not necessarily need to have identical orthography or phonology. For example, effects of the co-activation of languages have also been observed in the processing of cross-language orthographic or phonological neighbors, and these effect vary with the degree of orthographic and phonological overlap across languages (e.g., Font, 2001; Schwartz, Kroll, & Diaz, 2007). In a word naming study, Schwartz and colleagues presented Spanish-English bilinguals with cognates that varied on orthographic and phonological similarity across languages and noncognate controls. L2 naming of orthographically similar cognates (e.g., piano, base) was faster and more accurate than naming times of orthographically dissimilar cognates (train-tren, mark-marca). Furthermore, naming orthographically-similar cognates (e.g., piano, base) was slower and less accurate when the corresponding phonological codes in the two languages were more distinct (e.g., "base" in Spanish is pronounced as / ba se'/) than when the phonological codes were more similar (as in piano). Such an effect of phonology was not obtained in the orthographically dissimilar cognates (e.g., train-tren, mark-marca). This indicates that cognate processing is influenced by the consistency of the orthographic to phonological mappings in the bilinguals' two languages, such that competition from inconsistent phonology is most likely to be observed when the phonological representations map on to the same orthographic representations across languages. Likewise, Font (2001) showed that cognate effects were larger in identical than in non-identical cognates (cf. Duyck et al., 2007). Interestingly, recent studies using sign-speech bilinguals showed that the co-activation of languages in bilingual lexical processing it not restricted to languages in the oral modality, but

extends to languages from the spoken and visual modalities, speech and sign (Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011; Shook & Marian, 2010; Van Hell, Ormel, Van der Loop, & Hermans, 2009) or speech and gesture (Brown & Gullberg, 2008).

Observing consistent and robust effects of non-selectivity that persist irrespective of the language mode of the experimental situation, participant expectations, task demands, language-script or language-modality leaves unanswered the question of how bilinguals eventually do select language. Not finding a mechanism or source of selectivity in single word paradigms, some researchers turned their attention to possible influences from context. There are several possible sources of selectivity from context. First, the language of the written context itself might allow for earlier language selection based on activation within the target lexicon. Second, conceptual or semantic constraints in a sentence context may facilitate language selection via top-down activation of appropriate lexical entries, above and beyond the language cue the sentence context provides. Third, syntactic constraints in the sentence may help rule out cross-language competitors that cannot be accommodated within a particular syntactic structure. We next review evidence for each of these different potential sources to constrain lexical activation to a single language.

Language Cues From Context

Available evidence suggests that the first potential source, language of the surrounding words, is not an effective mechanism for language selection. For example, highly-proficient Dutch-English bilinguals performed a language-general lexical decision on word triplets (responding “no” only if one or more stimuli in the triplet was not a word in either language) (De Bruijn et al., 2001). The first word could be in either language and, on critical trials, the second

was an interlingual homograph and the third word was semantically related to the English-specific meaning (e.g., *HOUSE-ANGEL-HEAVEN*). Lexical decision times and N400 priming of the English-specific meaning instantiated by the third word were unaffected by the language membership of the first word in the triplet. Thus, the simple presence of words in a specified language is not sufficient to allow for selective activation of one language.

Later studies using full sentences as context produced convergent findings demonstrating a limited role of the language membership of context. [1] In fact, two separate studies using different language pairs (Dutch-English and Spanish-English) and bilingual populations showed persistent effects of cross-language lexical activation when critical cross-language competitors were embedded in a semantically-neutral sentence context. In one study, highly-proficient and intermediate proficient Spanish-English bilinguals were presented with all-L2 sentences word by word on a computer screen using a Rapid Serial Visual Presentation (RSVP) paradigm (Schwartz & Kroll, 2006). Their task was to name a target word (marked with a red font) out loud into a microphone. On critical trials the target words were either cognates in Spanish and English (e.g., piano) or interlingual homographs (e.g., pan in Spanish means 'bread'). Analyses on the naming latencies revealed significantly shorter naming latencies for cognates relative to noncognate controls when these were embedded in a semantically-neutral context which did not bias the meaning of the upcoming target word (e.g., 'When we entered the dining hall we saw the *piano* in the corner of the room.'). This result demonstrated continued language non-selectivity within a semantically-neutral sentence context. Van Hell and De Groot (2008; see also Van Hell, 1998)

[1] We will restrict the discussion to studies in which the target words and sentence context were presented in the same language. For studies that examined code-switched reading by presenting bilinguals with words embedded in sentences in the other language, see Altaribba, Kroll, Sholl, and Rayner (1996), Moreno, Federmeier, and Kutas (2002), Proverbio, Leoni, and Zani (2002). For a review, see Van Hell and Witteman (2009).

also presented bilinguals (native Dutch speakers who were highly proficient in English) with target cognate words within an all-L2 sentence context, this time with the lexical decision and word translation tasks. They observed significant cognate facilitation for both lexical decision and translation when cognates were in semantically-neutral contexts. Both studies also converged in finding an elimination of cognate facilitation when the cognates were embedded in sentence contexts that highly biased the meaning of the cognate (described in more detail below).

Recent eye-tracking studies have failed to observe any constraining influence on non-selectivity from the language context of a sentence. In a lexical decision and eye-tracking study by Duyck, Van Assche, Drieghe, and Hartsuiker (2007), Dutch-English bilinguals were presented with cognates and noncognates in their L2 English, preceded by a low constraint sentence context (e.g., I would like you to repeat that 'dance' (cognate) / 'smile (noncognate). They found that the cognate facilitation effect observed when the words were presented in isolation remained significant when the cognates and noncognates were presented after a low constraint sentence context which did not contain semantic cues that could bias the meaning of upcoming target words. This finding has recently been extended to reading in the L1, which should be particularly resilient to influences from the weaker L2 (Van Assche, Duyck, Hartsuiker, & Van Diependaele, 2009). Also in L1, the relative constraint of the sentence contexts did not modulate the processing advantage of cognates over noncognates.

Even hearing the language-specific phonology and phonotactics of the target language seems not to be sufficient to allow for language selective access. In an eye-movement investigation of the effects of context for auditorily presented sentences containing interlingual homophones (e.g., the French word, *poule* in French , meaning "chicken" and *pool* in English), highly proficient French-English bilinguals made more saccades to objects depicting the non-

target meaning of the homophones within a visual array, but only when the preceding sentence context was semantically plausible for both the target and non-target (e.g., "Marie va décrire la poule" (Marie will describe the chicken)) (Chambers & Cooke, 2009). Taken together these studies provide a strong case against the language of the context in and of itself as a source for selective activation of a single language.

However, in one study on bilingual sentence processing the ambient language of the experimental context did have an observable influence on language non-selectivity (Elston-Güttler, Gunter, & Kotz, 2005). In that study proficient German-English bilinguals performed a lexical decision on target words that were preceded by purely English sentences. On critical trials the sentences (e.g., 'The woman gave her friend a pretty') ended in an interlingual homograph (e.g., "gift" in German means "poison") and the follow-up target was related to the German meaning of the homograph (e.g., *POISON*). Critically, participants watched a short film in either English or German right before performing the lexical decision task. Both behavioral reaction time and ERP data showed priming of the German meaning of the homograph but only for participants who viewed the film in German and only during the first block of trials. Thus, unlike previous isolated-word paradigms, this sentence priming study revealed that the surrounding language mode can influence non-selectivity.

Semantic Cues From Context

Does semantic information from context modulate the co-activation of words in the non-target language? Stated differently, can information activated top-down from the semantic representation of the sentence influence the bottom-up processes of lexical access? Research on the influence of semantic constraints for monolingual readers has shown that sentence context

can influence lexical access and modulate word frequency effects (e.g., Van Petten & Kutas, 1990), lexical ambiguity effects (e.g., Simpson & Krueger, 1991), concreteness effects (see Schwanenflugel, 1991, for a review), and eye movements during reading (Rayner & Well, 1996). For bilingual reading, a sentence context contains semantic cues that bias a particular meaning, and thus can potentially constrain the activation of upcoming words. Relatively few studies have directly examined the role that semantic information from a sentence context may play in modulating cross-language activation in bilingual lexical processing (Elston-Güttler, Gunter, & Kotz, 2005; Libben & Titone, 2009; Schwartz & Kroll, 2006; Van Hell & De Groot, 2008). As we shall see, the available evidence suggests that the degree of language non-selective activation is affected by semantic characteristics of the sentence. So, as with monolingual processing, top-down processes of sentence comprehension and bottom-up processes of lexical activation interact in bilingual reading.

As discussed above, Elston-Güttler et al. (2005), Duyck et al. (2007), and Van Assche et al. (2009) had used one type of sentential context, weakly predictive sentences that did not strongly bias the activation of upcoming words (i.e., many words can complete the low constraining sentence 'I would like you to repeat that …' as used by Duyck et al., 2007). To gain more insight into the role of contextual constraint on bilingual lexical access both Schwartz and Kroll (2006) and Van Hell and De Groot (2008) manipulated the semantic bias of the sentential context preceding the target word. Schwartz and Kroll observed an elimination of the cognate facilitation effect in word naming when the to-be-named cognates were embedded in a sentence context that biased its meaning (e.g., 'Before playing the composer first wiped the keys of the *piano* at the beginning of the concert.' versus 'When they entered the large room they saw the *piano* that had been shipped from Italy'.)

To examine whether the top-down influences of semantic constraint is sensitive to subtle variations in semantic overlap of the target words, Van Hell and De Groot (2008) manipulated the concreteness of cognate and noncognate target words in addition to the semantic bias of the sentence context (an earlier study indicated that concrete translations, in particular concrete cognates, share more semantic features across languages than abstract words, Van Hell & De Groot, 1998). They found that in both lexical decision and translation, the cognate facilitation effect was modulated when these words were embedded in a high constraint sentence context, but not when embedded in a low constraint sentence context. The magnitude of the facilitation effect was not qualified by the concreteness of the cognates and noncognates, suggesting that the top-down influence of semantic constraint is not modulated by subtle differences in the degree of semantic overlap of target words' lexical representations across languages.

Libben and Titone (2009) provided more insight into the time course of lexical activation of words embedded in semantically biased and non-biased sentence context. They recorded eye-movements of French-English bilinguals while reading a high constraint or low constraint sentence context, followed by a cognate, an interlingual homograph, or a matched control word. When reading a low constraint sentence, both early-stage reading measures (first fixation, first pass gaze duration, and skipping rate; from initial fixation to approximately 350 ms later) and late-stage reading measures (go-past time, total reading time; approximately 350-600 ms after first fixation on target word) showed a cognate facilitation and a homograph inhibition effect. This finding indicates that low constraint sentence contexts do not modulate nonselective lexical access and cross-language activation, and corroborates the findings of Schwartz and Kroll (2006), Duyck et al. (2007), and Van Hell and De Groot (2008). Interestingly, in the high constraint sentences, Libben and Titone also observed effects of cross-language activation, but

only in the early-stage reading measures (first fixation and gaze duration) and not in the late-stage reading measures. This study thus indicates that while a constraining semantic context does not fully eliminate cross-language activation, it does restrain parallel activation to the early stages of target processing.

Syntactic Cues From Context

A third source of contextual constraint that may guide lexical access in bilingual word recognition are syntactic cues. For every possible combination of two languages there will be syntactic features that are unique to one language alone, some that are not present, and others that are expressed differently in the other language. Such syntactic features potentially restrict lexical activation to one language only, thereby constraining activation of lexical alternatives in the nontarget language. Remarkably, there is little empirical work that examines whether, and if so how, syntactic constraints affect bilingual lexical access, and how syntactic constraints may facilitate selection of lexical entries in a particular language.

Language specificity of syntactic structures has been found to affect bilingual language processing in other domains, including the acquisition of syntactic structures in the L2 (e.g., Tokowicz & MacWhinney, 2005; for a review, see Van Hell & Tokowicz, 2010) and code-switching (e.g., Deuchar, 2005; Kootstra, Van Hell, & Dijkstra, 2010; Poplack, 1980). More specifically, the ease of learning syntactic structures in a second language depends on the similarity of structures in the learners' first language, L1. For example, in an ERP study, Tokowicz & MacWhinney (2005) asked native English speakers who had just started to learn Spanish as an L2 to read Spanish sentences with and without syntactic violations. Sentences had syntactic structures that were either similar in Spanish and English (auxiliary omission), different

in Spanish and English (determiner number agreement), or unique to Spanish (determiner gender agreement). The learners demonstrated P600s in response to violations for the similar and unique constructions, but not for the different constructions. This indicates that whether or not syntactic structures are similar, different, or unique across languages affects their acquisition in a second language. The language specificity of syntactic structures has also been found to influence code-switching, the switching between languages which is a hallmark of fluent bilingual processing (e.g., Deuchar, 2005; Kootstra et al., 2010; Poplack, 1980). Linguistic corpora of code-switched utterances suggest that syntax constrains code-switching in the sense that switching is more likely to occur at positions where the syntax of the two languages is the same (e.g., Deuchar, 2005; Poplack, 1980). In a series of experiments, Kootstra et al. (2010) asked Dutch-English bilinguals to describe a picture after being cued with word orders that were similar across the two languages, or unique to one language. Although this was not the main question of this study, the data indicated that bilinguals were more likely to switch between languages after the shared syntactic cue than after the language-specific cue. In contrast, they more often used only one language when cued by language-specific syntax as compared to shared syntax. Language-specific syntactic cues thus evoked bilinguals to more often use only one language.

On the basis of research in these other domains of bilingual language processing, we can infer that syntactic constraints also potentially modulates lexical access in word recognition. Conceivably, sentences with high syntactic constraint (with language-specific, or unique syntactic features) constrain lexical access as opposed to sentences with low syntactic constraint (sentences with language non-specific features, syntactic features that are shared between two languages). Do syntactic constraints function like semantic constraints in reducing cross-language competition? A first study suggests that this may indeed be the case. Gullifer, Dussias,

and Kroll (2010) presented Spanish-English bilinguals with cognates and noncognates embedded in sentences with language specific syntax (high syntactic constraint) or language non-specific syntax (low syntactic constraint). Bilinguals were asked to name the cognates and noncognate targets. The bilinguals' naming data showed that cognate effects were only present in the low syntactic constraint sentences, where the sentence syntax was not specific to only one language. This first study thus suggests that syntactic constraints can function like semantic constraints in reducing but not eliminating cross-language competition in lexical processing.

Implications for models of bilingual lexical access

One of the first and most-often-cited connectionist models of bilingual lexical access is the Bilingual Interactive Activation Model (BIA; Grainger & Dijkstra, 1992; Dijkstra, Van Heuven, & Grainger, 1998) and its successor the BIA+ (Dijkstra & Van Heuven, 2002). A fundamental assumption of the BIA is that there is an integrated bilingual lexicon. Thus, when the system is provided with an input string word candidates from both languages are simultaneously activated. The assumption of parallel activation in two languages allows the model to account for the non-selectivity observed in bilingual word recognition. Most central to the present review on sentence context effects is the structure and operation of "language nodes" in the two models, one node for each of the bilingual's languages. The language nodes are connected to all the words of its language in the lexicon and they are the mechanism in the model that allows for the *potential* of language selection. In its first formulation, the language nodes of the BIA collect activation from both linguistic (activation of lexical entries) and non-linguistic (e.g., language context of the experiment) sources of information. As a language node collects activation, it sends top-down inhibition to words from the other, competing language. This top-

down inhibitory mechanism is what allows the system to operate in a language selective manner after an initial period of non-selectivity.

A fundamental change from the BIA to the BIA+ involved the operation of the language nodes. More specifically, in the later BIA+ the language nodes were no longer designated to collect activation from non-linguistic sources of information (such as the particular demands or instructions involved in the experimental task). Instead, extralinguistic sources of information operated outside of the lexicon within a task-decision system. This modification was motivated by accruing evidence that factors such as participant knowledge of the language of the task or language exclusivity of a task did not reduce observed effects of cross-language activation.

Findings from the studies reviewed here provide us with additional insight regarding the specific ways in which activated language nodes may allow for language selection. According to the BIA+ model, semantic information from a surrounding context can influence language selection in fundamentally two –mutually- interacting ways: First, it can allow for the language nodes to collect sufficient activation for lexical access to operate selectively. Second, the boosted activation of a language node for one language can allow it to more efficiently inhibit words from the competing language. Although it would be difficult to completely disentangle these two actions (activation of the language node is what allows for top-down inhibition), the available evidence suggests that context acts more directly on the second mode of action, top-down inhibition. Evidence from eye-movement studies is revealing that even in semantically highly-constraining sentences there is an initial period of non-selectivity. This suggests that there is little opportunity for the language nodes to become sufficiently pre-activated to allow for selective access based on semantics from the onset. Instead, what the biasing semantic context can do is allow the language nodes to exert top-down inhibition more quickly, consequently narrowing

the time-course over which non-selective activation is observed. Thus, in eye-tracking studies such as Libben and Titone (2009) cognate facilitation and homographic inhibition were only observed in early measures of the eye-movement record such as first fixation and gaze duration. Emerging findings from sentence context studies also highlight ways in which current models can be further developed. For example, it is not clear if there are types of linguistic context other than the semantic context that the language nodes in the BIA+ are sensitive to. For example, are they sensitive to fine-grained distinctions in semantic constraint? Or are they exclusively responsive to more coarse-grained sources of information such as language membership of preceding words? And to what extent is the activation of language nodes affected by syntactic constraints in the sentence?

Modeling sentence context and lexical access

Research on sentence context effects on lexical access has been specifically concerned with whether context can allow for selective access of a word's meaning within a language. This focus has been fueled by on-going debates regarding the degree to which language processing is modular or interactive across different levels of processing. If language operates in a modular fashion, top-down semantic integration processes of sentence comprehension should not directly influence the bottom up process of lexical access. If, on the other hand, processing across levels is interactive, then semantic information activated through prior context should have the potential to directly modify lexical access. There are a variety of models of lexical access in sentence context and they differ most fundamentally in whether they assume exhaustive access of homonym meanings or allow for potential selective access. To discriminate between these two hypotheses researchers have used the general strategy of embedding semantically ambiguous homonyms in sentence contexts.

In a classic study, Swinney, Onifer and Hirshkowitz (1979) had participants listen to auditorily presented sentences containing lexical ambiguities (e.g., bugs) such as "Rumor had it that for years the government building had been plagued with problems. The man was not surprised when he found several spiders, roaches and other **bugs** in the corner of the room." At the offset of the ambiguous words participants performed a visual lexical decision on target words that were either related to the context appropriate interpretation of the ambiguous word, (e.g., *ant*), or related to the inappropriate meaning (e.g., *spy*) or were completely unrelated (e.g., *sew*). Participants' responses to the words relating to the contextually appropriate and inappropriate meaning were both facilitated, suggesting that the multiple meanings of "bugs" were activated irrespective of contextual constraint. Findings such as those from Swinney (1979) have been interpreted as strong evidence for modular theories of language. If the multiple meanings of ambiguous words are activated, irrespective of context, this would mean that the bottom-up lexical processes that lead to their activation are autonomous from top-down processing. The implication is that any observed semantic priming from sentence context that would seemingly support interactivity is in fact due to either intra-lexical priming and/or post lexical processing.

However, the assumption that effects of sentence context are due to intra-lexical priming has been challenged (Simpson, Peterson, Casteel & Burgess, 1989). In one study participants read visually presented sentences and named target words out loud. On critical trials the to-be-named target words (e.g., table) were preceded by an associatively related prime (e.g., chairs). The authors manipulated whether these words were presented in a normal sentence context (e.g., "John bought new *chairs* to go with his new *table*") or a scrambled context (e.g., "Four with to *chairs* his go John new bought *table*"). They reasoned that, if speeded lexical access of the target

words (e.g., table) were due solely to intra-lexical priming, than naming latencies should have been equally fast for targets, irrespective of whether they were embedded in normal or scrambled sentences. In contrast, if contextual priming was indeed due to the higher level, semantic information of the sentences, than priming should have only been observed in the normal sentence conditions. The results showed significant priming for targets, only when they were embedded in normal sentences. In a second experiment the scrambled sentences were replaced with sentences that followed English syntax, but did not make sense (e.g., "The *author* tried many whispers on his back *book*"). Once again there was significant priming for targets only when they were embedded in normal sentences. These findings, overall, provided a strong argument against the claim that effects of priming in sentence context were due solely to intra-lexical, associative priming.

Several hybrid models have since been formulated which assume a combined influence of rapid activation of alternative meanings and the surrounding semantic context of a sentence (e.g., Duffy, Morris & Rayner, 1988; Simpson & Burgess, 1985) (see Morris, 2002 for a review). In this chapter we highlight one such model in particular, the Re-ordered Access Model (RAM) (Duffy et al., 1988). Because this model provides an account for a reliable effect (the subordinate bias effect, described below) which lends itself easily to cross-language extensions, Schwartz and colleagues have recently extended its assumptions to bilinguals processing (Arêas & Schwartz, in press; Arêas, Yeh & Schwartz, in press; Schwartz & Arêas, 2010; Schwartz, Yeh & Shaw, 2008). Thus, this model in particular is described in further detail below.

One assumption of the RAM is that access of homonym meanings in context is exhaustive. Thus, all meanings receive activation, irrespective of semantic constraint. Second, the RAM assumes that the relative frequency of individual meanings influences the degree of

activation. Thus, a dominant meaning will be more strongly activated than a subordinate meaning. Third, activation levels of the contextually-instantiated homonym meaning are influenced by the extent to which the sentence context semantically biases that meaning. In this way, a subordinate meaning of a homonym can be more strongly activated if it is strongly biased by the sentence. A fourth assumption of the model is that activation of the non-instantiated meaning is unaffected by context. This implies that even if a dominant meaning is not biased by a sentence context, its relatively high frequency allows it to still be sufficiently activated to compete with other meanings.

Initial evidence for the RAM came from Duffy and others (1988). The authors compared eye fixations for two types of ambiguous words: words for which the frequency of the multiple meanings was similar (balanced words) (e.g., *bark*) and words for which one of the meanings was of a much higher frequency (biased words) (e.g., *port*). These words were presented in either neutral sentences, sentences that biased the dominant meaning, or sentences that biased the subordinate meaning. When biased words were presented in neutral context fixations were similar to non-ambiguous control words, suggesting that the highly dominant meaning was automatically activated and since the frequency of the subordinate meaning was so comparably lower, it did not compete for activation. When these same biased words were presented in sentences biasing the *subordinate* meaning, strong inhibitory effects emerged. Duffy et al. reasoned that the additional semantic support of the subordinate meaning provided by the sentence allowed the subordinate meaning to become activated within the same window of time as the dominant meaning. The resulting competition delayed eye fixations. Duffy and colleagues referred to the delayed eye fixations observed in contexts biasing the subordinate meaning of

ambiguous words as the "subordinate bias effect" and it has been replicated across several studies (Binder, 2003; Binder & Rayner, 1998; Kambe, Rayner & Duffy, 2001).

Modeling sentence context and lexical access: Implications for bilingual word recognition

The emerging finding that sentence context does not eliminate cross-language non-selectivity but rather alters its time-course is convergent with the major premise of the RAM. In a recent set of studies Schwartz and colleagues have examined how cross-language non-selectivity might further influence the time-course with which homonym meanings are activated, thus proposing a way to extend the RAM to account for bilingual processing (Arêas & Schwartz, in press; Schwartz & Arêas, 2010; Schwartz et al., 2008). The general strategy across these studies has been to present bilinguals with sentences containing a cognate that is semantically-ambiguous ("homonym cognates") within the target language of the sentence (e.g., the cognate pair *arms-armas*: in Spanish *armas* shares the subordinate meaning of "weapon"; the cognate pair *novel-novela*: in Spanish *novela* shares the dominant meaning of "story") and to systematically manipulate the semantic bias of the preceding sentence context. In one study (Schwartz et al., 2008), highly-proficient Spanish-English bilinguals read all-English sentence contexts (the entire sentence absent the last word) on a computer screen and made a button press to see the last word (the prime), which after 250 milliseconds was followed by a target word. The participants' task was to decide as quickly and accurately as possible whether the target word was related in meaning to the sentence they had just read. On critical trials the prime word was a semantically-ambiguous English homonym that was either a cognate with Spanish (e.g., *novel-novela*) or a noncognate (e.g., *fast*) and the preceding context biased its subordinate meaning (e.g., "She is an original thinker and her ideas are" [prime word "novel"]; "In observance of the

religious holiday the family observed the" [prime word: "fast"]). The follow-up target word was related to the contextually-irrelevant but dominant meaning (e.g., novel: *BOOK;* fast: *SPEED*) (thus requiring a "no" response). Bilinguals were slower and made more errors in rejecting the follow-up target word when the homonym prime word was also a cognate with Spanish (e.g., "novel"). The increased competition observed from cognate homonyms relative to noncognate homonyms suggests that cross-language co-activation of the dominant meaning increased the strength of its activation. In a variation of this study a new group of highly proficient Spanish-English bilingual performed the same task, however, this time the participants' task was to decide whether the follow-up target words were related to any meaning of the preceding homonym prime (e.g., *arsm* in English can mean either a "body part" or a "weapon") (Arêas et al., in press). On critical trials the sentence contexts biased the dominant meaning of the homonyms (e.g., "Tim fell out of the tree and broke his"[prime word: *arms*]") and the target was related to the non-instantiated subordinate meaning (e.g., *WEAPON*) (thus requiring a "yes" response). Bilinguals were faster and more accurate in accepting the follow-up targets as being related to a meaning of the prime word when the prime was a cognate homonym and the subordinate meaning was shared across languages (e.g., "*armas* in Spanish shares the subordinate English meaning "weapon").

Together these two reaction-time based studies provide converging evidence that cross-language activation affects the strength of activation of homonym meanings during sentence comprehension. This interpretation has recently received additional support from a study using eye-movement monitoring (Schwartz & Arêas, 2010). Highly proficient Spanish-English bilinguals read all-English sentences on a computer screen while their eye-movements were monitored. These sentences contained English homonyms that were either noncognates (e.g.,

bullets) or cognates (e.g., *arms*) with Spanish, and shared the subordinate meaning ('weapon'). When the sentence context up until the critical word was neutral (e.g., "There were too many **bullets** under the heading and the slide was not clear." there was no difference in processing time for noncognate homonyms and nonhomonym controls. When these same noncognate homonyms were embedded in a context biasing the subordinate meaning (e.g., "His slides had too many **bullets** and were difficult to understand.") the mean first fixation duration was significantly longer than controls, thus replicating the subordinate bias effect. More critically, processing time for cognate homonyms was significantly *longer* than controls in both neutral and biasing contexts (e.g., "The man placed his **arm** on the table to pass through security check.", "The man fired his **arm** when the robber entered his house.") This demonstrates that co-activation of the subordinate meaning was sufficient to allow this meaning to compete with the dominant meaning even in the absence of support from a biasing context.

Based on these studies Schwartz and colleagues have proposed an extension of the RAM- the Bilingual Re-ordered Access Model (B-RAM). This extended model adds a third factor, cross-language activation, which is assumed to influence the activation of homonym meanings for bilinguals. The B-RAM shares the four assumptions of the RAM listed above. However, critically it adds cross-language lexical activation as a third factor that influences activation levels of instantiated homonym meanings (in addition to relative frequency and sentential context). Thus, when a subordinate meaning of a homonym is a cognate meaning across a bilingual's two languages, the coactivation will allow it to become sufficiently activated to compete with the dominant meaning, even in the absence of a biasing context, as observed by Schwartz and Arêas (2010). This phenomenon has not been previously observed with any of the monolingual investigations of the subordinate bias effect cited above. The key implication is that

due to language non-selectivity bilinguals can activate subordinate meanings early on, in the absence of a biasing context..

Future Directions

Published systematic and focused investigations on the effects of sentence context on bilingual lexical access have only recently begun to appear, with most studies appearing after the year 2000. This is despite the fact that psycholinguistic studies on the effects of sentence context on lexical access have more than a thirty-year history. From the relatively few studies published to date it is clear that our understanding of the cognitive dynamics guiding sentence comprehension will be incomplete without the inclusion of bilingual manipulations. For example, for years there has been a debate regarding whether information from sentence context directly influences lexical access. Yet only very recently have we learned that language membership does not provide a powerful cue to allow for selective access within a language but rich, semantic information can constrain the time-course of language non-selectivity. Emerging evidence provides some suggestion that syntactic information can have a similarly-constraining effect on language non-selectivity- but more research is clearly needed. Yet another example of the need for bilingual research is the fact that studies dating back twenty years ago demonstrated that a critical component of fluent reading is the ability to efficiently sustain activation of weaker meanings of ambiguous words (e.g., Gernsbacher & Faust, 1991). Yet only recently have we learned that bilinguals might be at an advantage for activation weaker meanings when these are co-activated across languages.

The lack of studies that specify the features of contextual information that constrain lexical activation is another gap in the available bilingual literature. Such studies are needed in

order to fine-tune theoretical models on lexical activation in bilingual word recognition. In the last decade, many studies on isolated word processing studies appeared in the literature on bilingualism, the next step is to extend this to perceiving words in more naturalistic contexts. Furthermore, bilingual sentence context studies have focused on two oral languages from the same script. In order to develop theories and models of bilingual sentence processing that fully specify the relative contributions of different potential sources of constraint, more evidence is needed on coactivation in different-script languages, and sign-speech or gesture-speech. Another dimension of sentence processing that requires further specification is the time-course with which lexical competitors are activated during sentence processing. Recent eye-tracking studies have produced effects of cross-language activation even in semantically-rich sentences but only in aspects of the eye-movement record that tap into earlier stages of processing. There is a need for more studies using methodologies that can further elucidate the time-course of activation such as eye-tracking and ERPs. Finally, a hallmark of bilingual language processing is the flexible switching between languages, both in the production and the perception of language. However, as of yet, the majority of studies on lexical access in context focused on studies in which the language of the context was the same as the language of the target. To what extent does our current knowledge on lexical activation in bilinguals apply to lexical access in code-switched sentences?

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