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REVIEW ARTICLE

A review of the theories of lexical access and storage in bilinguals

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Review

Abstract Knowledge of two languages has several psychological and linguistic consequences for bilingual speakers. Some of them have been widely explored, such as lexical storage or phonological transfer between languages, whereas others, related to the impact of the languages in higher cognitive processes, have been barely studied. In this article, a review of the theories of lexical storage and lexical access of the bilingual speaker is presented. This review emphasises the evolution of the research methodologies through time, and how they have affected the construction and testing of theoretical proposals. With this paper, we intend to set the basis of deeper insights into bilingualism and its psycholinguistic features.

PALABRAS CLAVE
Acceso léxico;
Almacenamiento léxico;
Bilingüismo;
Revisión

Revisión de los modelos de almacenamiento y acceso al léxico de los bilingües

Resumen Conocer 2 idiomas tiene diversas consecuencias psicológicas y lingüísticas para los hablantes bilingües. Algunas de ellas han sido ampliamente exploradas, como el almacenamiento léxico o la transferencia fonológica, mientras otras, relacionadas con el impacto de las lenguas en procesos cognitivos superiores, apenas han sido estudiadas. En este artículo se presenta una revisión de las teorías de almacenamiento y acceso al léxico en hablantes bilingües. La revisión enfatiza la evolución de las metodologías de investigación en el tiempo, y el impacto que estas han tenido en la elaboración y en la comprobación de dichos modelos. Con este artículo se sientan las bases de futuras investigaciones que profundicen en el bilingüismo y sus características psicolingüísticas.

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Introduction

Q3 Since the end of the 19th century, psychologists and linguists have been exploring how speakers represent their knowledge about language: the sounds, the letters, the meanings, and how they all relate to each other. Clarification of the psychological processes behind language has been (and still is) an arduous task. This is particularly complex in the bilingual speaker's mind, giving rise to further questions: how do bilinguals store their linguistic knowledge, integrated into a global linguistic unit, or separated into two different languages? The landscape gets more complicated when considering the definition of bilingualism, as opposed to second language acquisition, the existence of a critical period for language learning or the difference of language learning and language acquisition (Krashen, Butler, Birnbaum, & Robertson, 1977; for a more complete view of the issue, see Harley, 2011).

Several models have been proposed, and an enormous amount of empirical evidence has been collected. Theoretical proposals have varied over time, incorporating technological advances and allowing researchers to delve into such interesting questions, finding answers for some of them. In the last decades, several neuroimaging techniques have also contributed to developing models of lexical access and storage by comparing the neural activity of different profiles of speakers. In this paper, we present the evolution of the main models of lexical access in bilinguals.

Lexical access and storage

Lexical access can be generally defined as the process by which speakers retrieve their representations of words from their lexicon or ''mental dictionary'' (Altmann, 2001, p. 135; Finkbeiner, Gollan, & Caramazza, 2006, p. 153). Lexical storage then refers to the way in which these mental representations are kept and organised in such ''dictionary''. However, these definitions call for further clarification of several aspects.

Firstly, we need to define what *words* are. According to Cuetos, González and De Vega, words are the smallest units of language that have a meaning (Cuetos, González, & De Vega, 2015, p. 149). In fact, our mental representation of a word contains several kinds of information:

- Phonological: we know the sounds of the words, so we are able to both pronounce and recognise them. Whenever we hear /gːl/, we recognise the word 'girl'.
- Orthographical: we also know how words are presented in written form, and thus we are able to read and write them.
- Morphological: the word 'girl' is a feminine singular name, so no addition or modification is needed to convey the right meaning. If we were speaking in plural, the plural mark '-s' should be added, forming the word 'girls'.
- Syntactic: as 'girl' is a noun, it can play different roles in a sentence. It works as a subject in ''the girl was wearing a blue dress'', and as a direct object in the sentence ''she went to pick the girl up from school''.
- Semantic: we can convey what the word 'girl' means, a feminine child, differencing it from related words, such as 'boy', 'woman' or 'teenager'.

Secondly, it is essential to remind that these various pieces of information are not stored as a single block in our mind or as a well-defined entry in our lexicon. Rather, information about words is stored in different units, corresponding to the various kinds of information mentioned above (phonology, orthography and so on; Dijkstra, 2005, p. 180). When presented with a word (either in oral or written form), information about that word is activated and retrieved from each level to conform a holistic representation. Thus, the mental representation of a word is constructed when needed, but is not stored as a closed package of information. This process of activation and retrieval takes place in a matter of milliseconds.

The third clarification regarding words is the difference between lexical access and lexical storage. The first process refers to the activation of the information needed for communicating a given meaning, whereas the second refers to how this information is kept in our mind. The two processes are different but highly interrelated. In fact, the access to the words will vary depending on how the information about these words is stored.[1] Therefore, most of the models hereby presented contemplate both parts of the process: the nature of the information we keep in our minds, and how we access to or activate it.

This issue of storage of linguistic information is especially relevant when studying bilingual speakers. The fact of knowing two languages implies a somewhat different organisation of information compared to monolinguals. Do they store linguistic information of both languages in a single unit or in two separated networks? Are the nodes of these networks shared, at least partially? If so, does the risk of confusion between languages increase?

These are some of the questions that the theoretical models included in this review aim to answer. Some of them address these matters directly from a bilingual perspective, and some of them are adaptations of monolingual processing models. They are presented in a chronological fashion, as for to make evident the evolution of the theories over time.

Evolution of the models of lexical access and storage in bilinguals

Researchers have been intrigued by the bilingual mind since the end of the 19th century, suggesting different proposals as to how bilinguals store and access their knowledge of

[1] Several other factors may have an influence in accessing lexical representations: psycholinguistic factors such as the type of word or the frequency, the language of the word (whether it belongs to the first or second language, and how these two interrelate, as well as the characteristics of each language), whether it is presented in a written or oral form, with or without a context or sentence (previously processed words from the context might facilitate the activation of a given word), how the vocabulary has been learnt (in a spontaneous or instructional fashion). A full account of all the possible intervening factors falls out of the scope of this article.

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the languages. The very first models were based on direct observation of the development of bilingual children, often in an informal setting, as well as on reflections of bilingual adults upon their own way of thinking and speaking in their two (or more) languages. With the evolution of scientific methodologies, new measures were incorporated to the research on bilingualism: response times, priming experiments, eye tracking and so forth. Later on, the development of computer technologies allowed for more sophisticated proposals: computer programmes were designed to simulate neural networks and their behaviour with language. These programmes were first taken as a means to test whether the theories, elaborated on the evidence gathered with traditional tests, were suitable. However, the latest proposals are directly programmed in these neural simulations, and only after their computational suitability has been ensured, they are tested against evidence from experiments. Neuroimaging techniques have also made a fruitful contribution to the study of the neural correlates of psycholinguistic processes.

First models

The first accounts of bilingual studies are found in the last decades of the 19th century[2] and first decades of the 20th. Psychologists studied psycholinguistic phenomena by direct observation of monolingual and bilingual subjects, and also of monolingual aphasic patients (Pitres, 1898). Some researchers even asked bilingual subjects to execute very simple tasks and asked for their self-reports on such activities. Epstein (1915), for instance, presented students of a French university some pictures paired with their name in a foreign language, and asked them to write the French name of the items. He also collected the reflections of these students upon their processes when reading or speaking the languages they knew. Based on these data, Epstein suggested several of the issues that bilingualism would study for the next century, ranging from how words in different languages are stored, the importance of the context for language selection, or the most adequate age to learn a foreign language.

Several accounts of the development of language in bilingual children were also published at the beginning of the 20th century. Ronjat issued in 1913 his observations of his son Louis, who learnt German and French in a one-person/one-language fashion (Ronjat, 1913). A few years later, Leopold published his observations of the linguistic development of her first daughter, who was raised in a similar way: each of her parents spoke to her in a different language, English and German respectively (Leopold, 1939). Both accounts show that children acquired their two languages without apparent difficulties, and that they were able to adapt to the interlocutor.[3]

It is interesting to point out that, at the beginning, bilingualism was seen as prejudicial for intellectual development (Epstein, 1915, p. 87; Weinreich, 1967, pp. 116–122). Still, these first researchers' work has been very useful to see how the bilingual lexicon develops, and the great influence that the linguistic environment exerts in this process. One of the first theories proposed for the bilingual lexicon managed to reflect this influence of the context. In his work, Weinreich (1967) reviewed several studies of bilinguals, taking into account the typological distance between languages and the socio-cultural environment as key factors. According to this author, the proximity of languages, or even of dialects, and the use of the languages in the social context, had a great impact in how bilingual speakers developed their mental dictionary.

Based on his extensive work, Weinreich had previously suggested a difference between coordinate and compound bilinguals (such distinction was made in 1953, as reviewed by Siguan Soler & Vila Mendiburu, 1991). A coordinate mental lexicon would have word forms stored in two separate units, one for each language, and a shared unit for meanings. This would be the profile of a bilingual that has been exposed to both languages from an early age and on a balanced way. However, if the bilingual speaker is more proficient in one language than in the other, the linguistic systems are not yet integrated, and both words and meanings from the first and second language are kept separated. The mental lexicon would be compound, made of two separated units. The different associations between languages and ideas was already described by Epstein (1915), who, based on his subjects' self-reports, suggested that both the proficiency reached in the foreign language and the way it was learnt had an influence on how words and concepts were connected.

Around the time of Weinreich's publications, MacNamara (1967) suggested that the integration or separation of words and meanings in a single lexicon is a continuum rather than two separate options. He conducted several experiments with college students (Irish-English speakers and English speakers that studied Latin in their religious career) and concluded that the situation of bilingual speakers on that continuum depends on their personal circumstances and their history of language acquisition.

An example of a continued, integrated lexicon was set by the Dual Coding Hypothesis proposed by Paivio and Desrochers in 1980. They suggested that words could be stored under two forms: a verbal form and an image (Paivio & Desrochers, 1980). Concrete words (e.g. 'bread' or 'niña') would have both types of representation, whereas abstract words (e.g. 'justice' or 'amistad') would only be represented with a verbal form. Therefore, bilinguals could share the imagery system between languages, but have two separated lexicons, one for each language. This model implies that the links between concrete words in the two languages, such as English 'bread' and Spanish 'pan' is stronger than between 'friendship' and 'amistad', because the former would share at least the imaginal representation, and the latter would share nothing.

[2] I would like to thank the anonymous reviewers of the article for widening my view on the field of bilingual studies, among other very useful suggestions.

[3] Little is said in Leopold's memories about his second daughter, who did not become bilingual despite the one-person/one-language policy followed in her education. Aronsson (2018) suggests that the lack of play partners who spoke German (Leopold and his family lived in the US) and the schooling of the elder sister in an English-speaking school biased the children's interactions towards English, favouring this language over German.

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Following this Hypothesis, Paivio and Lambert (1981) enriched this view of the bilingual lexicon suggesting that high frequency words (usually concrete words), as well as those concepts which are very similar in both languages, would be stored closer in the ''dictionary''. Low-frequency words and those concepts which are language-specific or have no direct translation equivalents would be kept apart in their respective language lexicons.

Paradis' studies with bilingual English-French aphasic patients (Paradis, 1985) confirmed this integrated conception of the lexicon, which he reflected in his Subset Hypothesis: the two languages of a bilingual are stored in a single linguistic system, but they are separated in different, autonomous subsets, according to several factors such as language, proficiency, means of instruction or frequency of use.

Regarding the creation of models of access to these stored representations, there were several questions to be answered. Firstly, access to words would greatly depend on how these were stored: if there was one lexical storage for each language, access should be language-specific; that is, bilingual speakers would only look for an item in the correspondent storage unit. However, if words were stored in one single space for both languages, was access language-specific and only words in the target language were accessed, or words in both languages would compete for selection? A second issue was related to the relationship between first- and second-language lexical items, for the researchers wondered if they were connected among them (e.g., if the words 'girl' and 'niña' had a direct connection) or if such connection happened through the meaning, through an intermediate semantic level. Several proposals were suggested, as reviewed by Kirsner and colleagues (Kirsner, Smith, Lockhart, King, & Jain, 1984), which contemplated various possibilities. Another topic that generated controversy was the channel through which the input arrived: whether the lexicon was accessed through phonology, orthography, or both. Finally,[4] the task was also seen as an intervening factor in accessing words. As Soares and Grosjean (1984) suggest, there are tasks that aim for accessing the meaning of the word, activating all possible levels of information, whereas other tasks only pretend to access the lower levels of information about a word, such as the orthographic representation (for instance, when the task consists on answering comprehension questions, versus a proof-reading task).

Most of these issues were difficult to observe in naturalistic settings, but the development of experimental methodologies facilitates the researchers' task.

Descriptive models

The second generation of models of lexical access was built on observation of bilingual speakers in experimental settings, while doing linguistic tasks such as word and picture naming or word translation. These experimental techniques allowed researchers to register reaction times (RTs) and eye movements, and elaborate theories based on empirical evidence. Later on, with the development of computational machines, computer programmes were eventually developed to mimic how speakers used their languages, testing the researchers' assumptions against these neural network simulations. The development of such technologies also implied a change on the vocabulary: these second generation models borrow from computers the metaphor of depicting language processing as a network with interconnected units or nodes.

Around the time when Paradis presented his observations, several psychologists and linguists were studying other possibilities through experiments with healthy bilingual speakers. McClelland and Rumelhart (1981), for instance, presented an interactive description of linguistic processes for monolingual speakers that was quickly adapted to the bilingual situation by Paap and colleagues (Paap, Newsome, McDonald, & Schvaneveldt, 1982). The original Interactive Activation model of McClelland and Rumelhart suggested that at the presentation of a visual stimulus, a written word, all lexical items that shared some letter with the input would be activated. For instance, when reading the word ELEPHANT, all those words that shared letters with it would receive activation: 'easy', 'elf', elegance', and 'elephant'. The amount of possible candidates was reduced as more letters from the input were incorporated ('E-', 'EL-', 'ELE-' and so on). The lexical item with the greatest overlap with the input would be selected, and the activation flow would then access the meaning of the word.

The bilingual version of the model, the Bilingual Interactive Verification Model (Paap et al., 1982) followed this access mechanism, but added a new component: a verification mechanism that checked if the selected coinciding item is in the target language, according to the task at hand. If our subject was a Spanish-English bilingual, the items 'elefante' and 'elephant' would both be highly activated, as most of the letters coincide with the input, ELEPHANT. In an English to Spanish translation task, the unit we would be searching for is 'elefante', the Spanish translation equivalent, and the verification mechanism would select it and inhibit the English word. If we were just reading in English instead, our verification mechanism would select 'elephant' in the target language, and reduce the activation of the competitor 'elefante'.

Another monolingual model that was further developed into a bilingual model was that of Seidenberg and McClelland: the Distributed Model of Word Recognition and Word Naming (1989). These authors conceived linguistic knowledge in a similar fashion to neural networks. Linguistic units are nodes, connected in an extensive network. These nodes store different kinds of information: phonological, orthographical, and semantic. According to Seidenberg and McClelland's proposal, an input word would generate a unique pattern of activation of several nodes. Repeated joint activation of such units would define that specific pattern as the representation of that specific word.

The bilingual version of this model was issued by Soler and Van Hoe in 1994. This Bilingual Access Representations model incorporates a set of ''hidden units'' that process

[4] Several other topics have been investigated in relation to lexical access and representation, such as cross-linguistic transfer, translation, research with cognate words and homophones, or code-switching. However, an extensive review of all the implications of how words are stored and activated falls far from the more general overview offered in this article.

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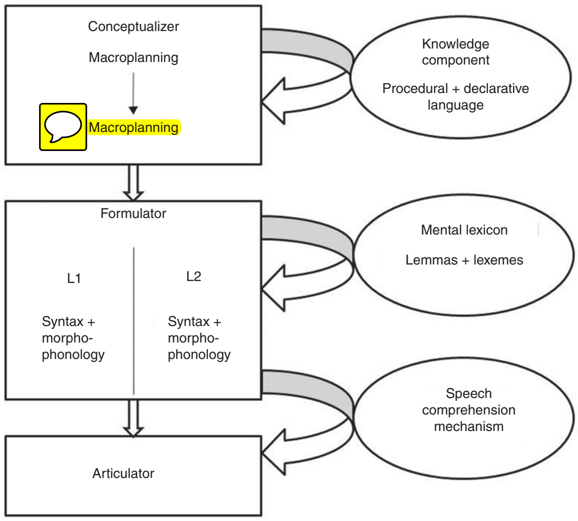

Figure 1 Representation of the adaptation of the Speaking Model of Levelt to the bilingual speaker by De Bot (1992). Source: R. Ferrer-Xipell.

information regarding the task at hand, as well as the language of the input (Soler, 1995).

The third important monolingual proposal from the 80s was the Speaking Model of Levelt,[5] issued in 1989; it has been one of the most accepted proposals in the psycholinguistic field, and has given rise to several bilingual processing models. Levelt's model focused on linguistic production, instead of comprehension (Levelt, 1989). The preverbal message is planned by a conceptualizer unit, in which the ideas to be expressed are defined. This conceptualizer combines the communicative goals of the speaker with the world's knowledge stored in the long term memory, in order to choose the ideas for the message.

The selected concepts are then passed down to the formulator, in which the specific words that convey such ideas are chosen and given an adequate syntactic role. This verbal message goes on to the articulatory unit, which translates the message into sounds. Before it is actually emitted, a supervisory mechanism ensures the correctness of the ideas and words selected, and the order in which they are presented. If the message is correct, it is emitted by the speaker. If a mistake is detected, the message is returned to the formulator to be corrected (Fig. 1).

De Bot (1992) adapted Levelt's proposal to bilingual speakers. The message planning also starts in the conceptualizer, but in addition to the usual task, the conceptualizer must also choose in which language the message is to be emitted. The language is selected according to the context, the interlocutor and the task at hand.

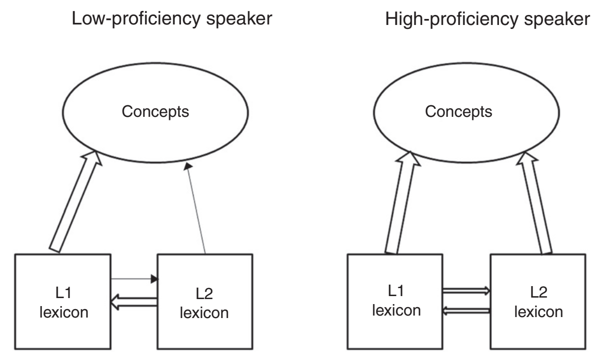

Figure 2 Representation of the different profiles described in the Revised Hierarchical Model by Kroll and Stewart (1994). Source: R. Ferrer-Xipell.

When the preverbal message passes on to the formulator, where word features are stored in a shared fashion, only those items in the target language will compete for selection.[6] The process continues as usual: the form encoding and articulatory units construct the definitive message, and before it is emitted, the supervisory mechanism comes into play. This time, the mechanism checks for correctness and adequacy, and also for language: the sentence must be in the target language determined by the conceptualizer.

A fourth proposal was issued by Kroll and Stewart in 1994: the Revised Hierarchical Model (RHM). It has been one of the most important theories of lexical access in bilinguals for decades. This model states that concepts and meanings are shared by the two languages of the bilingual speaker, whereas word forms are stored separately. Depending on the degree of proficiency of the speaker in the first and second languages, words will have a stronger or weaker connection with the ideas they represent. First language (henceforth, L1) items have fast and strong connections with their meanings. However, a weak knowledge of L2 (the second language) implies that the connection between the word and its meaning is weak. Thus it demands of the speaker to seek for the L1 translation equivalent in order to gain access to the semantic meaning. As proficiency in L2 increases, direct links between L2 words and their meanings gain strength, and translation is no longer necessary to access meanings when using the L2 (Kroll & Stewart, 1994) (Fig. 2).

Kroll also participated in the elaboration of yet another model, alongside De Groot: the Distributed Lexical/Conceptual Features model (Kroll & De Groot, 1997). According to these researchers, concepts in both languages shared features. They proposed the existence of three levels of representation of linguistic information: a shared repository of conceptual features, a language-specific repository of lemmas, and a shared repository of lexical features. Thus, bilingual speakers would share part of their linguistic knowl-

[5] Levelt's Speaking Model and its bilingual adaptation present lexical access from a different point of view. Whereas most of the models reviewed in this article explain access to words and meanings within comprehension processes, Levelt (1989, 2001) and De Bot (1992) explain how words are accessed in the top-down process of constructing a message. This perspective of lexical access is particularly enriching because it presents us with the dilemma of language-selective access to words when preparing an output: do concepts activate both their L1 and L2 corresponding units? Or is language selected in the conceptualisation of the message, such that only lexical items in the target language will compete for selection?

[6] Poulisse and Bongaerts (1994) suggest the existence of language tags within de Bot's model. If words had tags indicating, among other features, the language they belong to, the search for the correct item would be faster and easier.

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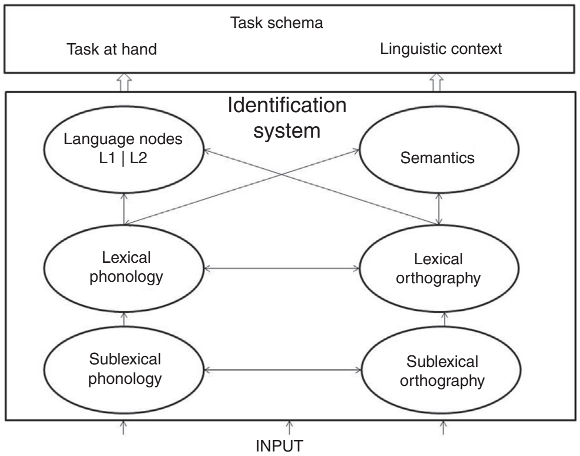

Figure 3 Representation of the Bilingual Interactive Activation + Model by Dijkstra and Van Heuven (2002). Source: R. Ferrer-Xipell.

edge between languages, and they would keep apart the language-specific units.

Statistical models

The previous proposals were based on empirical evidence from observation and experiments, and did not use the computer simulations for elaborating the theoretical framework. At most, they used computerised programmes to test whether the results obtained in their experiments were mimicked by the neural network simulations. However, from the late 80s and during the 90s, several models were developed that used these neural simulations not to test their theories, but to build them. This third generation of models is constructed upon the possibilities that the computational simulations offer. Once they are built, the simulation results are compared to those gathered from experiments, in order to see to what extent the computer is a successful imitator of real speakers.

The following proposals have in common the network structure that allows for two new features on the theories of lexical access: learning and self-organisation. These networks are computer programmes based on mathematical algorithms that are trained by the researcher. These algorithms ''learn'' from experience: if a set of nodes is activated jointly and repeatedly, the system learns to answer to that specific stimulus with that specific pattern of activation. This flexibility allows the network to self-organise the information it stores, clustering nodes according to various principles (nouns together with nouns, L1 items with L1 items, and so on). Computerised networks configure their own layers and maps, varying the strength of connection between units and layers (Fig. 3).

The first models developed with this technology were monolingual models of lexical storage, and they were localist; that is, one node stands for one word (Ritter & Kohonen, 1989). Progressively, the networks shifted from localist to distributed: words were not identified with a single node, but with a pattern of activation of several nodes. The new models included several layers of networks, differentiating semantic networks from phonological and orthographic ones (Li & Zhao, 2013; Li, Farkas, & MacWhinney, 2004; Li, Zhao, & MacWhinney, 2007; Miikkulainen, 1997). Researchers were even able to mimic brain damage and study how language works in speakers with aphasia or dyslexia (Miikkulainen, 1997).

The first distributed model that directly addressed the issue of bilingualism was published in 1997: BIMOLA, the Bilingual Interactive Model of Lexical Access, by Léwy and Grosjean (reviewed in Grosjean, 2008; Thomas & Van Heuven, 2005). According to these authors, there are three different layers of linguistic information: the first one includes phonological features, and is shared between the two languages. The phonemic and lexical networks are language-specific: the nodes form two separated clusters, one for each language.

Lexical access occurs in the following fashion: an acoustic wave activates the phonological network; this network passes on the activation to the phonemic level, and then to the word level. Because the phonological level is shared, one single string of sounds might activate phonemes in both of the languages; for instance, the string TOMATO might activate both English word 'tomato' and Spanish 'tomate'. A top-down mechanism checks whether the selected word matches the language of the input.

A second model addressing bilingual lexical access was the Bilingual Interactive Activation (BIA) model by Grainger and Dijkstra (Dijkstra, 2005; Grainger & Dijkstra, 1992). These authors distinguished four different layers of information: features, letters, words and language. Input is language non-selective: activation flows from feature and letter levels to words in both languages. When activation arrives at the language node level, the system compares their levels of activation. Generally, one of them is slightly more activated than the other, because the input matches best items from one language than from the other. Following the previous example, the input TOMATO would lead to a higher activation of the English node, in comparison to the Spanish one, because the input matches the lexical unit 'tomato' more accurately than the lexical unit 'tomate'. Activation flows back from the language level to the lexical one, maintaining activated the units in the target language, and inhibiting the nodes from the unwanted language.

An update of the BIA model, named BIA+, was issued in 2002 by Dijkstra and Van Heuven. This new version included a new layer that conveys semantic and syntactic information; it also distinguished between orthographic and phonologic information. It would receive activation from the word level, before it reached the language node level (Dijkstra & Van Heuven, 2002). These authors also suggested that a supervisory mechanism was also necessary, in order to incorporate information from the task at hand (Fig. 4).

Similarly, in 2005 MacWhinney updated a previous proposal for language acquisition (MacWhinney, 1987) and issued the Unified Competition Model (MacWhinney, 2005, 2008), a proposal that explained both L1 and L2 language learning. MacWhinney's model consisted on several associative maps of information, which he calls 'arenas': phonological, morpho-syntactic, lexical, and semantic. These arenas are Self-Organised Maps that are able to learn by continually adjusting cue strength after repeated activation of items. Another key component of the model is competition: input generates cues between word forms and

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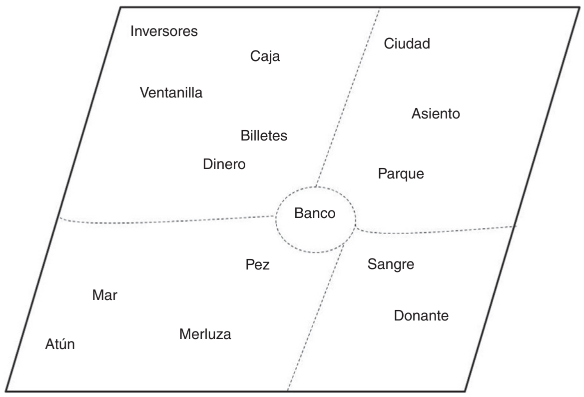

Figure 4 Representation of a Self-Organised Map. Nodes representing words cluster together by proximity of meaning. Source: R. Ferrer-Xipell.

meanings, and these items compete for selection. The form-meaning connection with the strongest and more valid cue is chosen.

The bilingual Unified Model contemplates the mutual influence of the languages or codes the speaker possesses: transfer from L1 to L2 is possible, especially when the second language is still weak and less proficient. As the speaker earns proficiency in this second language, the associative arenas adjust to create proper links among L2 items, less dependent of L1 items. The initial sharing of L1 items between first and second language would explain phenomena such as code-switching (cues to certain L1 items are stronger than to their L2 equivalent items) or the foreign accent of L2 learners (L1 phonology is more easily accessed).

One of the particularities of this model is a useful strategy to speed up processing: information that is usually activated together, such as a verb and a proposition, forms chunks or blocks, which facilitate access to that specific set of features. Chunking would also facilitate the development of fluency in L2, as it is easier and faster to build sentences with bigger packages of information, instead of going piece by piece.

The most recent proposal of this kind is the BLINCS model, the Bilingual Language Interaction Network for Comprehension of Speech, elaborated by Shook and Marian (2013). This model is also developed on Self-Organising networks, clustered in four levels: phonological features, phono-lexical, ortho-lexical and semantic. The middle layers, phono-lexical and ortho-lexical, represent the oral and written forms of words, and are highly interconnected.

An interesting particularity of this model is the addition of a visual information level. The model is designed to account for listening, not reading, and thus, this extra layer incorporates information from the environment that might alter the way an input is processed. For instance, it might help the listener to distinguish between words that have similar pronunciations by reading the lips of the speaker. The authors also contemplate the idea that visual information from the context in which the interaction takes place has some impact in the attribution of meaning: a given utterance can be seen as an offence or as a joke, depending on the serious or exaggerated gestures of the speaker.

Another characteristic that makes BLINCS a unique model is that it incorporates vector space techniques to its networks: all the layers are made of vectors, very much as in mathematical models such as HAL[7] (Hyperspace Analogue to Language; Lund & Burgess, 1996). These statistical models ''learn'' languages through the co-occurrence of words and concepts in the input, and thus they are able to reflect the distribution of semantic information based on real data from real texts, very much like children learn vocabulary in an inductive, implicit fashion (Lund & Burgess, 1996).

Hybrid models

In the last decade, a new proposal[8] has emerged that aims to combine the strengths of the descriptive models with the endless possibilities of the computational networks. This proposal is the Multilink model, by Dijkstra and Rekké (2011). It is a combination of the two most important theoretical models of bilingual lexical access: BIA/BIA+ and the Revised Hierarchical Model. From the first one, Multilink takes the structure, distinguishing between semantic, orthographical and phonological information, and language membership. It also borrows the task/decision system. From the RHM, Multilink assumes the different size of L1 and L2 lexicons, although they are not separated. The connections between lexical items and the semantic level may vary from L1 to L2 depending on proficiency and word frequency, as Kroll and Stewart contemplated in their proposal.

Multilink has been implemented for word translation: input activates phonological or orthographical units, depending on the modality in which the stimulus is presented. Activation flows to the semantic levels and then to the language nodes, which register the language of the input. In accordance with the information of the task component, the language nodes select the language of the output, and the activation flows down to the phonological/orthographical units, in which the output is selected. A novelty with respect to the BIA/BIA+ model is that Multilink spares the sublexical layers: it does not include letter and feature layers, but directly represents words as phonological or orthographical units. By introducing this change, Dijsktra and Rekké increased the efficacy of the model, with no alteration of the accuracy of the results (Fig. 5).

Regarding the contributions of the RHM, Multilink uses the resting level activation to reflect both proficiency and frequency: the resting level will be higher if the words are frequently used or belong to the more proficient language. The fact that the lexicon is integrated, instead of separated, allows the model to mimic cognate and neighbourhood

[7] The Hyperspace Analogue to Language consists on the representation of meanings of words as multidimensional vectors in a high-dimensional space. Vectors are calculated with the co-occurrence of the studied words in different contexts (Burgess, Livesay, & Lund, 1998; Lund & Burgess, 1996).

[8] Although new models have been elaborated (for instance, Fang, Zinszer, Malt, and Li (2016), they do not introduce revolutionary novelties; they rather represent variations of previous proposals. Perhaps an exception is the CASP model for bilingualism (Filipović & Hawkins, 2018), although it does not focus on lexical access.

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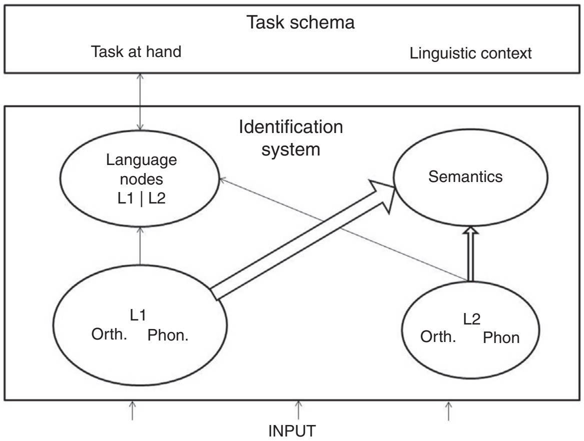

Figure 5 Representation of the Multilink model by Dijkstra and Rekké (2011). Elements from both the RHM and the BIA+ can be recognised. Source: R. Ferrer-Xipell.

effects at the three levels: phonological, orthographic and semantic.

Contribution of neuroimaging techniques

Several neuroimaging techniques have been applied to the study of the bilingual brain, giving support for some of the proposals reviewed in this article.

For instance, studies of the brain activity have shown that the bilingualism shapes the brain in a different way to that of monolingual speakers, both structurally and functionally (Grundy, Anderson, & Bialystok, 2017). Research has also shown that the bilingual's two languages have a somewhat different representation on the brain: although they share the activation of general linguistic areas, the patters of L1 and L2 activation are different depending on the level of proficiency and the age of acquisition of each language (Xu, Baldauf, Chang, Desimone, & Tan, 2017). Bilinguals' patterns of neural activation have also been studied as compared to monolinguals' (Kovelman, Baker, & Petitto, 2008).

A full account of all the contributions of neuroscience to the research field of bilingualism would exceed the purpose of this article. However, it is important to note that interesting results have been published regarding the role of bi- and multilingualism in delaying cognitive deterioration; there are also numerous articles on the impact of bilingualism on general cognitive mechanisms.

Conclusions

The theories of lexical access and storage have changed over time. They have been modified by the empirical evidence and the development of new technologies. The present review does not cover every theoretical proposal; however, it manages to give an overview of how psycholinguists have progressed in their want of knowledge about what happens in our minds.

One of the greatest limitations of this field is the impossibility to see what is actually happening in the brain when we use language. Neuroimaging techniques have helped scientists identify which areas of the brain are in charge of linguistic processes, and have also proved that language is related to more general cognitive processes, such as attention and perception.

The computerised simulations give researchers an idea of how our brain might work, but as for today, there is yet no way of comparing how similar these simulations are to the actual functioning of the brain.

Despite the present limitations, knowledge of psycholinguistic processes has become deeper and wider, building solid theories on empirical evidence and technological development. The Multilink model seems to be able to replicate the speaker's behaviour in several aspects: word translation, neighbourhood effects, interlingual cognates and so on. Although further investigation is needed in order to incorporate morphology and syntax, it is quite a strong framework to work with.

As for the future, there are several fields of this science that ask for a closer and deeper look. One of them is the concrete pair of languages a bilingual speaker knows. Does the type of languages of a bilingual and their distance have any influence in the organisation of lexical knowledge? Do different scripts generate different orthographic layers?

A second unexplored field is the relationship between what we learn and the language we learn it in. To what extent are semantic and lexical knowledge independent? Does language have any influence in general cognitive mechanisms, such as inference generation or learning strategies? For instance, if bilinguals learn reading comprehension strategies in L1, would they be able to apply them to their L2? We hope to address some of these matters in future research projects, widening our view of bilingualism and of the psychology of language.

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Conflict of interests

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