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WORD PROCESSING IN BILINGUALISM. A SCOPING REVIEW BASED ON EVOKED POTENTIALS

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Abstract

Event-related potentials (ERP) allow us to analyze the processes involved in language comprehension with high temporal precision. Bilingual people show particular functional patterns in these processes, as a result of the use of two or more linguistic systems in their daily lives. The aim of this review is to present the main components of ERPs involved in word processing and recognition in bilinguals. For this purpose, an exhaustive search of indexed journals was carried out and 16 original research articles were selected and classified into three categories: sub-lexical factors involved in recognition, semantic factors, and translation process. It was found that learning a second language generates changes in brain activity from the initial stages of learning. However, a time lag is observed in comparison with the first language. The processing and recognition of words in a second language are favored by factors such as morphology and phonetics, as well as the emotionality of the stimulus. It is concluded that methodologically all studies present a characteristic pattern, which corresponds to early, middle and late moments in word recognition. Finally, future lines of research are discussed.

Keywords: *psycholinguistics, bilingualism, recognition, semantic memory, EEG*

The acquisition and use of other languages, known as bilingualism, is a widespread phenomenon in different countries and societies.[1] Research on the subject has shown that bilingualism produces neuroanatomical and functional changes.[2] The highly complex information processing involved in language occurs in a short period of time - its properties can be identified in milliseconds, whether they are words or phrases in the mother tongue (L1) or in a second language (L2)[3-5] - so research in this area requires techniques and instruments that are coupled to the characteristics of the phenomenon. Within the set of neuroimaging techniques, event-related potentials (ERP) are a useful measure of electroencephalic activity for the study and analysis of the neurophysiological processes involved in language processing, specifically in the case of bilingualism.

The general objective of the present literature review is to address the issue of bilingualism from its neurophysiological study, with emphasis on ERP measures. To this end, in the first instance, the theoretical aspects that are considered key to understanding the data obtained through ERP will be developed. In a second instance, experimental studies on word recognition in people who use a second language will be presented.

Event-related potentials

ERPs are electrophysiological responses that are recorded by an electroencephalograph (EEG) after being exposed to a specific event. EEG allows continuous recording of brain electrical activity. By contrast, ERPs, as derived techniques, allow isolation of the time studied in relation to the stimulus-event presented.[7] Therefore, many researchers resort to this technique to study the neural events involved in language processing and production.

ERPs are displayed as waves associated with underlying components of brain activity.[6,7] Each of the ERP components is identified according to certain criteria, such as polarity (positive or negative) or latency (time of onset after stimulus presentation).[8] In addition, it is relevant to recognize whether brain activity patterns vary according to different conditions. These differences are mainly observed in amplitude, i.e., the average voltage within a specific time window.[6] For example, the N400 component,[9] one of the most studied, is associated with semantic processing. Its polarity ("N" indicates negative) and latency (400 milliseconds after stimulus presentation) can be derived from its nomenclature. In the case of this component, the difference in amplitudes between two conditions is called the "N400 effect" and is associated with difficulty in semantic integration within a context,[10,11] as well as in accessing semantic information, and varies according to the lexical properties of a word, such as familiarity.[12,13]

Another type of terminology used maintains the polarity and replaces latency by the position of the deflection in the ERP continuum. In this sense, the P3 component refers to the third positive deflection, while N1 refers to the first negative deflection.[14] Others, however, integrate approximate latency, electrode location and polarity. Examples of this type of components are the late positive component (LPC), whose amplitude increase is associated with the reinterpretation and reanalysis of the stimuli presented, or the early posterior negativity (EPN). The diversity of criteria in terminology represents a problem because it interferes with the possibility of comparing the results of different studies.[15] However, the ERP technique remains a reliable way to identify differences and similarities in information processing, and is useful for studies related to perception,[16] response production[4] and other cognitive abilities.[17]

While EEG and ERPs have been widely used for the study of language, it should be considered that not all language experiences are equal. For more than 50% of the world's population,1 knowledge of two or more languages and their everyday use is the norm. This phenomenon, known as bilingualism, opens new questions about the organization of language in the brains of speakers. Several authors have proposed that the organization of information in bilinguals is different from that of monolinguals,[18-20] as it involves the coexistence of two or more different linguistic systems.[21,22] From this perspective, the ERP technique provides indispensable information to characterize the way in which these populations perceive and recognize lexical items, as well as to identify the similarities and differences of their neural substrates necessary to obtain a comprehensive understanding of the phenomenon.

Based on the contents developed and considering the objective of the present review, a retrospective and systematic study of scientific research focused on the study of language processing in a bilingual population using ERP as a central measure will be presented below.

Methodology

Sample

Sixteen empirical articles were selected after a search in indexed scientific journals and the incorporation of secondary sources. This process was carried out between December 2021 and June 2022. Inclusion criteria were: (a) empirical studies addressing word recognition in a bilingual population; (b) studies using the ERP technique; and (c) studies comparing latency and/or amplitude of evoked potentials. Articles were excluded based on the following criteria: (a) studies older than 10 years from their publication date; (b) studies with samples composed of professionals (interpreters); (c) studies conducted in populations with neurological or psychiatric pathology and/or clinical trials; (d) studies conducted with sign language users; (e) computational modeling studies; and (f) studies using more complex verbal stimuli (paragraphs or sentences) to investigate effects on minimal units of meaning.

Procedure

In the literature search, a review protocol was applied, designed by the authors, and organized in four stages. In the identification phase, a general search was carried out with the keywords "word recognition" AND bilingual AND (eeg OR erp) to identify the paradigms used in the area. In addition to the 318 articles found, thirteen studies selected from relevant secondary sources were included. After elimination of duplicate records, a total of 293 articles were selected for the comprehensive abstract reading.

Subsequently, in the screening phase, the 293 articles were evaluated according to their fit with the research objective and inclusion criteria: 211 articles failed to meet any of the inclusion criteria, 49 were pre-selected in the eligibility stage for full reading, and 33 were also eliminated for meeting any of the exclusion criteria.

From this selection of articles, a database was designed, detailing: (a) number of persons in the sample; (b) sample size and classification; (c) experimental paradigm; (d) type of stimuli; (e) ERP component analyzed; (f) electrophysiological results found. Each article was evaluated according to internal consistency, considering the objective of the review. Finally, in this instance of inclusion, the final selection for the qualitative synthesis was obtained, composed of sixteen articles (Figure 1).

Results

A total of sixteen research articles met the data extraction requirements. The articles were divided by their thematic axes into three groups. In the first, the main ERP components involved in recognition when morphological manipulations are involved are presented. In the second, the relationship between brain activity and semantic (lexical) factors involved in word recognition, including the recognition of emotional content, is detailed. This differentiation is traditional in cognitive models of word recognition,[23] regardless of the language of presentation. Figure 2 illustrates these models. Finally, the third model analyzes the components related to translation processes, a particular skill of those who have acquired an L2.

Morphological changes resulting from the acquisition of an L2
The acquisition and use of an L2 produces anatomical and functional changes at the cerebral level.[24,25] This phenomenon can be characterized as the incorporation of new strings of symbols associated with specific meanings, which implies that the acquisition of new vocabulary in a language system different from the L1 produces changes at the physiological level. Regardless of the languages used, these changes derive from the time of consolidation of this information (see Table 1, which discusses the main results of studies on the subject). In their study, Soskey et al.[26] observed changes in the N400 component over the course of learning an L2. For this, the researchers assessed L2 learners over the course of a semester (3 sessions) using a lexical decision task, in which they were asked to discriminate words (e.g. city) from pseudowords (e.g. pook) in L1 and L2, while their brain activity was recorded with EEG. The authors expected that, when comparing words and pseudowords, the amplitude of the N400 component would change, reflecting the correct incorporation of novel words (in L2) into the lexicon. In line with their hypothesis, they found a progressive increase in N400 amplitude across sessions unique to L2, indicating that the consolidation of novel semantic units produces changes at the electrophysiological level. Differences in the N400 component between L1 and L2 decrease with increasing L2 proficiency, that is, as the frequency with which participants interact with the L2 increases.

However, the morphological characteristics of the stimuli confer different levels of complexity to word recognition.[27-30] Two articles focused on investigating how these features affect word recognition in a bilingual population, inquiring about the way in which written words with morphologically complex structures are processed at different stages of L2 learning. On the one hand, Lehtonen et al.[31] compared word recognition in bilinguals who acquired their L2 in the first years of life and

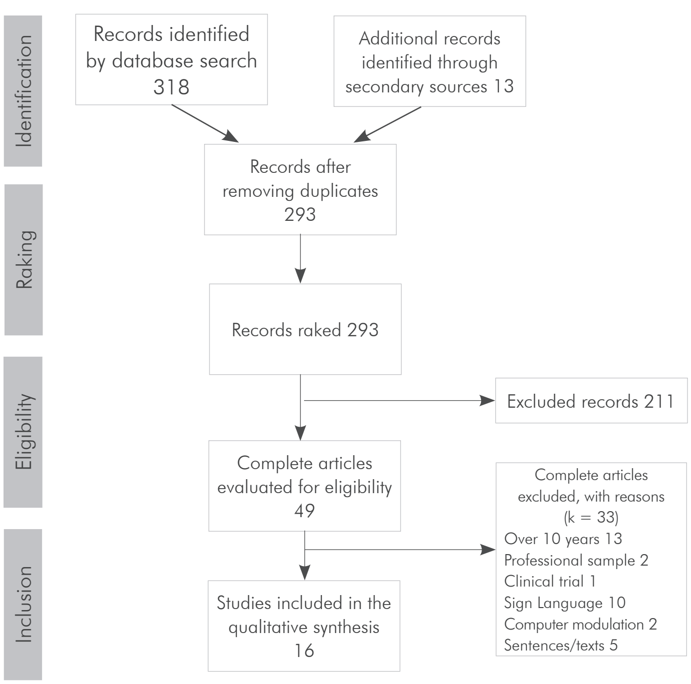

Figure 1. Flow chart of item selection.

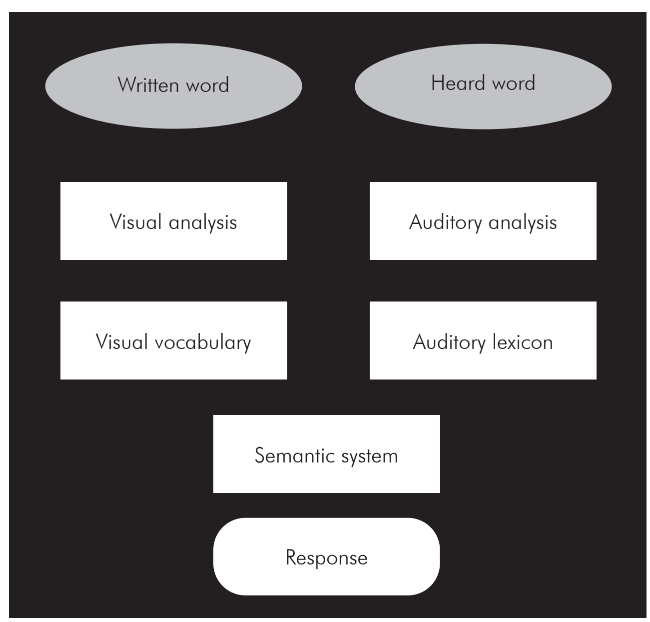

Figure 2. Simplification of the word recognition model proposed by Ellis.[23]

Table 1. Synthesis of results: morphological factors involved in the ERP response.

Reference	Sample&	Design/Task	Comparison	Component	Analysis windows	Results
(26)	Students L2	Vocabulary training program	Language: L1 vs L2	pre N400	200 - 350 ms	L1 > L2
	(N=12)		Distribution: Anterior vs Posterior	N400	350 - 600 ms	L1 > L2 in posterior sites
		Sesión: 1 *vs* 2 *vs* 3				Sesión: 3 > 2 > 1
				post N400	600 - 800 ms	L1 > L2 in posterior sites
						L1 < L2 in posterior sites
(31)	BS (N=16)	TDL	Lexicality: Words vs. Pseudowords	N400	250 - 350 ms	No differences
	MS (N=16)		Frequency: HF vs LF		350 - 450 ms	No differences
			Morphology: Monomorphic vs Polymorphic		450 - 550 ms	Pseudowords > words (longer in BS)
						BF > AF en BL
					550 - 650 ms	Pseudowords > words (longer in BS)
						Monomorphic > Polymorphic in BS
(32)	EL2 High proficiency (HP; n = 15)	Priming	Group: AD *vs* BD	N400	350 - 400 ms	HP: not related > related only morphological pairs
	EL2 Low proficiency (LP; n = 16)		Morphological pairs: related vs. unrelated		400 - 450 ms	HP: not related > related only morphological pairs
			Semantic pairs: related vs. unrelated			HP and LP: not related < related semantic pairs only
			Spelling pairs: related vs. unrelated			HP and LP: not related < related semantic pairs only
						HP and LP: not related > related only orthographic pairs
					500 - 550 ms	HP: not related > related only morphological pairs
					550 - 600 ms	No differences

Note: BS: bilingual sample; MS: monolingual sample; L1: first language/dominant language; L2: second language; LDT: lexical decision task; AS: number of associated senses; LF: low frequency; HF: high frequency; LPC: late positive component/complex; EPN: early posterior negativity; SOA: Stimulus onset asynchrony.

in monolinguals. Participants performed a lexical decision task in the language used by the monolingual participants. This task presented two experimental manipulations: the frequency with which a word appears in the language (low *vs.* high) and its morphological structure (simple, such as light, *vs.* complex, such as inflection). The results showed that the N400 component presented a higher latency in bilinguals than in monolinguals. In addition, in the case of bilingual participants, low-frequency simple words showed greater negative amplitude than high-frequency complex words. From these results, the authors argued that bilinguals are more sensitive to stimulus manipulation than monolinguals, since bilinguals had to simultaneously access two-word representations instead of one. It is for this reason that a longer latency, i.e., a delay in the onset of N400 is observed in bilingual versus monolingual participants.

In turn, Liang and Chen[32] assessed the recognition of complex words in bilingual participants with high and low L2 proficiency. The authors used a repetition priming design, according to which a faster and more accurate response was expected to be observed if the word, or a part of it, had been seen before. The researchers designed three conditions for morphologically (walking [prime] - road [target]), semantically (smile - laugh) and orthographically (plant - plan) related word pairs, which were compared with unrelated pairs (smile - plant). In the morphological condition, high-dominance bilinguals showed a priming effect for related words compared to unrelated pairs in three temporal windows (350-400 ms, 400-450 ms, and 500-550 ms). This effect manifested as an attenuation in the N400 component, which showed greater positivity in trials involving morphologically related pairs. While in the semantic condition this effect was not observed, in the case of the orthographic condition the priming effect was present in later temporal windows (400-450 ms and 450-500 ms). It is worth mentioning that no differences were found by language domain, since both groups showed the same response patterns. It has been observed that, in a monolingual population, N400 amplitudes to a target stimulus decrease, i.e., become more positive, when the *prime* stimulus has activated some of the properties of the target stimulus and/or made it more predictable.[9] In this case, Liang and Chen argue that such differences in the morphological condition are due to the L2 domain conferring the ability to decompose the presented word. The morphological priming effect would be relevant because it reflects the ability to manipulate words as a native speaker would. When the high proficiency bilingual observes the *prime* caminando he/she is able to discriminate root (camin-) and inflection (-ando), which leaves a mnemic trace that facilitates access to the target word (camino). High-dominance bilinguals, on the other hand, would store each lexical item completely, which would prevent them from applying a decomposition rule. In this sense, while high-dominance bilinguals would store the root of a word (camin-) in order to combine it with other suffixes (camin+o, camin+ante, camin+ata), low-dominance bilinguals would store the whole words as single items (camino, caminante, caminata). This explanation accounts for why orthographically related pairs (plant - plan), which do not require a decomposition, also observed a priming effect in N400: both the high-dominance and low-dominance groups are equally sensitive to orthographic manipulation. On the other hand, the absence of a priming effect in the semantic condition in both domains would indicate that, although the meaning of the words is recognized, this is not sufficient to leave a mnemic trace that activates the properties of the target stimulus.

Both studies would indicate that the morphological level - unlike other levels of analysis, such as the phonological - would be particularly sensitive to changes in word recognition in bilinguals, which would present electrophysiological markers that would point to a better recognition of the changes produced. This decomposition ability would exclusively benefit the recognition of morphologically related words, while semantics and orthography would depend on the speaker's level of proficiency.[32] In this line, the main component analyzed was the N400.

Semantic factors involved in L2 word recognition

So far, studies focused on morphological manipulations have been presented, however, word recognition also occurs at a lexical-semantic level, i.e., through representations of the whole word with its meaning (Table 2). Taler et al.[33] used a lexical decision task in English and in English and French to assess word recognition in monolinguals and bilinguals, respectively. The words to be recognized were grouped according to their semantic richness: words with a high number of associated meanings and words with a low number of associated senses. The authors found that words with low semantic richness corresponded to a higher negative amplitude in N400 compared to those with high semantic richness, and this was true for both groups. As in previous studies, increased N400 (i.e., greater negativity) is interpreted as a difficulty in processing information. In this case, access to semantic information is facilitated when the word has several associated senses. To corroborate possible differences within the bilingual group, the authors compared their performance in L1 and L2, and found that this difference in amplitudes was only observed in L2. This could be explained by the relative experience that monolinguals and bilinguals have with language. Since bilinguals' communicative experiences occur in two different languages, the apprehension of different meanings and the frequency with which they appear may be split between L1 and L2. In contrast, in the case of cognates, words that share meaning, spelling and/or pronunciation in two languages, such as the word animal in Spanish and English, these words would be expected to be facilitated.

Peeters et al.[34] took this hypothesis to study how semantic knowledge and lexical frequency interacted in bilinguals. To do so, they performed a lexical decision task in L2 (English), in which they compared cognates, control words (non-cognates) and pseudowords. In turn, they manipulated the frequency with which each word appeared, generating high and low frequency groups in L1, in L2 or in both languages. Overall, the researchers found that high-frequency words, in L1 and L2, showed lower N400, suggesting that frequency facilitates the integration of these words. When contrasting only cognate and control words, they found a similar pattern: cognates showed lower N400 compared to control words. The authors also found that word type modulated a second component, the LPC component, in which cognates also showed lower amplitude compared to control words, indicating that only the latter would require further reanalysis.

These results were replicated by Bice and Kroll,[35] who performed the same task and semantic comparison (cognates *vs.* control) with beginning and intermediate L2 learners, whom they compared to a monolingual sample. In that study, cognates produced a lower N400 in both L1 (monolinguals) and L2. Taken together, the results of both studies can be interpreted as an initial facilitation in cognate processing, which is evidenced by an attenuation in the N400 component, and by a greater need for reanalysis of control word information in the case of Peeters et al.,[34] who found greater positivity in the LPC component.

Thus, bilinguals are sensitive to changes in words at the semantic level and, as seen in the previous section, the results depend on the level of L2 dominance. In the studies of Taler et al.[33] and Lehtonen et al.,[31] the differences can be explained as a product of a lower exposure to L2 words by bilinguals. The N400 component is systematically involved in all studies; although tentative results pointing to a reanalysis of the information were found, only one investigation included the analysis of components temporally later than N400, such as LPC.

Within the semantic level, another topic of interest is the emotional meaning of words. Studies in monolingual population indicate that emotional content also functions as a *prime* stimulus, replicating the effect of N400,[36] and that there are specific ERP components for this type of stimuli.[37,38] On the one hand, the EPN is a component that is observed between 250 and 350 ms after presenting a stimulus with emotional content. When this component is presented sequentially with LPC, it is interpreted as the attentional capture and subsequent processing of the emotional information presented.

Emotional experiences can be identified by valence, which indicates the level of pleasantness of a word (positive words are the most pleasant, negative words are the most unpleasant), and activation, which indicates the degree of arousal it generates.[39-42] Regarding how these findings translate to the bilingual population, Opitz and Degner[43] hypothesized that, if there is a lower emotional response in L2,[44] a reduction of the EPN component should be observed for emotional words in L2 compared to words in L1. In their study, participants were instructed to perform a lexical monitoring task, in which they identified pseudowords orthographically similar to real words with emotional content. The authors found that emotional words generated greater negative deflections than neutral words in the 280 to 430 ms temporal window. By dividing this temporal window every 50 ms, they found that emotional words modulated the EPN component in both L1 and L2. However, the valence effect in L1 occurred in the earliest section of the temporal window, indicating that emotional words in L2 are processed with delay compared to words in L1.

Chen et al.[45] found different results from the previous study. To assess emotional word processing in bilinguals, they examined the EPN and LPC components in a lexical decision task with emotional content. The authors found that both components were modulated according to emotional valence, although only for words presented in L1. In the case of EPN, positive words generated greater negativity than neutral words, while for LPC negative and neutral words generated greater positivity than positive words. When analyzing the temporal windows with 50 ms of lag, they found that neutral words in L2 produced a pattern similar to that of the N400 component. In contrast to previous studies, neutral words in L2 induced greater negativity than positive words, indicating that word access and integration was facilitated in the case of bilinguals when the semantic content was emotionally positive.

In second language learning, some authors postulate that learners attend to the emotional content of words earlier in

Table 2. Synthesis of results: semantic factors involved in ERP response

Reference	Sample&	Design/Task	Comparison	Component	Analysis windows	Results
(33)	MS (N=17)	TDL	Associated senses: High AS and Low AS	N400	300 - 600 ms	MS y BS: Low AS > High AS
			Group: MS vs BS			AS x Group: Low AS > High AS only in MS
	BS (N=18)		Language: L1 vs L2			BS L1 vs L2: Low AS > High AS in L2
(35)	BS	TDL	Lexicality: Words vs. Pseudowords	N400	300 - 400 ms	L2: HF > LF
	(N=19)		Language: L1 vs L2		400 - 500 ms	L2: HF > LF; cognates and control
			Frequency: HF vs LF			L1: HF < LF only in cognates
			Semantics: cognates vs. control		500 - 600 ms	L2: HF > LF
				LPC	600 - 700 ms	L2: HF > LF only in cognates
						Control > Cognates
					700 - 800 ms	Control > Cognates
					800 - 900 ms	Control > Cognates
(34)	MS	TDL	Semantics: cognates vs. control	N400	300 - 500 ms*	L1: No cognates > cognates
	(N=25)		Group: MS vs Students			L2: No cognates > cognates
	Students L2		Proficiency: Intermediate vs. beginning students			L2: intermediate > beginners
	(N=36)		Language: L1 vs L2			
(43)	BS	TDL	Latency: L1 vs L2	EPN	280 - 430 ms	Emotional > neutral words
	(N=32)		Emotionality: emotional vs. neutral words			Language x time interaction: delay in L2 relative to L1
(45)	St. 1: BS	TDL	Emotionality: Pos vs Neu vs Neg	P1 y N2	250 - 400 ms	No differences
	(N=24)			EPN	250 - 350 ms	L1: Positive > neutral words
						L2: No differences
				LPC	450 - 500 ms	L1: No differences
						L2: No differences
					500 - 550 ms	L1: Positive < neutral words
						L2: No differences
					550 - 600 ms	L1: Positive < neutral words
						L1: Positive < negative words
						L2: No differences
(46)	BS	Masked priming	Emotionality: Pos vs Neu	N1 / P1	80 - 150 ms	Translation: Related > Not related
	(N= 20)	Direction: L1-L2	Session: 1 vs 2			Pos > Neu
	Longitudinal		Affectivity: affective congruence (pos-pos, neu-neu) vs affective			Session: No differences
			Translation: related vs. not related	P2 / N2	150 - 300 ms	Translation: Not related > Related
						Affective congruence: No differences
						Session: No differences
				N400	350 - 550 ms	Translation: Related < Not Related
						Pos < Neu
						Session: Session 1 > Session 2
						Affective congruence x Translation: Related < Not related in congruent essays
						Affective congruence x Translation: Related > Not related in incongruent essays
				LPC	430 - 550 ms (prime)	Related > Not Related
					550 - 700 ms (blanco)	Pos > Neu
						Session: 2 > 1
(47)	BS	Masked priming	Emotionality: Pos vs Neu vs Neg	N400	300 - 500 ms	BS: not related > neutral words
	(N=15)					BS: not related > positive words
						MS L1: not related > neutral words
						MS L1: not related > positive words
						MS L1: not related > negative words
						MS L2: No differences
	MS			LPC	450 - 650 ms	BS: pos and neg words > not related
	(N=30)					MS L1: pos and neg words > not related
						MS L2: pos and neg words > not related

Nota. BS: bilingual sample; MS: monolingual sample; L1: first language/dominant language; L2: second language; LDT: Lexical decision task; AS: Number of associated senses; LF: Low frequency; HF: High frequency; LPC: Late positive component/complex; EPN: Early posterior negativity; SOA: Stimulus onset asynchrony; Pos: Pleasant/positive stimuli; Neu: Stimulus onset asynchrony; Neg: unpleasant/negative stimuli.

the learning process. To corroborate this idea, Sianipar et al.[46] used a priming paradigm with emotional words in adults enrolled in a five-week language course and analyzed early (N1, P1, N2, P2,) and late (N400, LPC) temporal windows during four assessment sessions. The aim was to assess sensitivity to the emotional content of the stimuli, for which positive and neutral words in L2 were preceded by *prime* words in L1 with positive, neutral and negative valence (affectively congruent and incongruent pairs). The authors observed electrophysiological changes in early and late windows in the recognition of emotional words in L2. From the first session, positive words showed a greater amplitude than neutral words in the N1 and LPC components, while the opposite effect was found in the N400 component. This would indicate that second language learners attend to the emotional content of words very early in L2 learning. However, given that the L2 words were preceded by L1 words, these could have activated the affective connotation.

To identify whether L1 presentation activates affective connotations in L2, Wu and Thierry[47] implemented a design that combines the priming paradigm with implicit and spontaneous translation by introducing a masked phonetic repetition. In this case, bilingual participants observed pairs of words related by emotional valence (positive, neutral, and negative) and unrelated pairs. On each related trial, participants observed a *prime* word with emotional valence (e.g., fra-caso) and then a word implicitly related through the repetition of a phoneme in L1 (e.g., fra-nela). On unrelated trials, this repetition was absent (e.g., weather-gender). In all cases, they were asked to indicate whether the words were related or unrelated. Importantly, to investigate whether this response was affected by phoneme repetition when automatically translating the stimuli from L1 to L2, bilingual participants responded to the task in their L2. Performance was contrasted with two native control groups in the L1 and L2 of the bilingual group. Comparing related and unrelated trials, the researchers found that in the bilingual group the positive and neutral pairs produced a lower N400 than the unrelated pairs (no implied phonetic repetition in L1). The same pattern was found in the L1 control group for all valence categories. In contrast, the L2 control group, for whom no trial presented phoneme repetition, did not present modulation in N400 in any of the above conditions, indicating similar processing for related and unrelated pairs. The authors argue that these results show a specific effect of valence on word processing in bilinguals. On the one hand, phoneme repetition is a modulating factor that facilitates word processing, evidenced by the lower N400 in all valence categories for the L1 control group. On the other hand, for bilinguals this effect was modulated by the valence of the presented pairs, as this facilitation was observed for positive and neutral pairs. This suggests that reading positive and neutral words causes coactivation of both languages, so that the repetition effect is maintained in the N400 component. However, reading neutral words, which did not produce this modulation, indicates a failure to activate translation equivalents in the L1, so that the response patterns are similar to those of the L2 control group, in which phoneme repetition was absent.

In sum, the studies presented indicate that emotional words in L2 present latency delays with respect to L1.[43] As observed in sub-lexical manipulations, this delay could represent a greater difficulty in accessing the semantic content of the word. One research team did not replicate the results for emotional content: Chen et al.[12] found a delay of 50 ms for neutral words in L2. All four studies described observed a bias in the processing of emotional words, either in L12 or in L1 and L2[43, 46, 47] evidenced by greater negativity to neutral words. This is interpreted as a greater attentional capture by this type of words. However, other research has already shown that both age of acquisition and L2 proficiency are key factors in understanding the operations underlying L2 processing (see Liang and Chen[32]), but none of these studies contrast these variables. On this issue, Wu and Thierry[47] indicate that both factors are insufficient to account for the specific effect of valence in modulating word processing in bilinguals. This is because, on their own, they do not provide sufficient grounds to assume that positive and negative words in L2 would be acquired in systematically different contexts, ages or periods of life to account for the observed psychophysiological variations. Nevertheless, further evidence is required to obtain conclusive definitions.

With respect to the ERP components involved, a discrepancy is observed regarding the nomenclature and function for specific components elicited by emotional content. Two studies defined EPN as the main component for emotional processing, whereas one selected N400, in agreement with investigations that did not use emotional stimuli. Since both components share polarity and temporal onset, these differences may be related to the experimental task used, with *prime* tasks favoring the occurrence of N400 and lexical decision tasks favoring the occurrence of EPN.

The translation process

One way of accessing semantic information in bilinguals is through explicit translation tasks, in which participants must identify the best translation for a word in a specific language. This process involves the person accessing information stored in the input language to reformulate a correct response in the target language (see Table 3 for a summary of studies). While translators and interpreters have an advantage in this type of task as a product of training, the need to translate is also inherent in the bilingual experience.[48] Chung et al.[49] evaluated the effects of morphological complexity on translation tasks in languages with different writing and combined a lexical decision task with a masked priming design to test bilingual participants. In study 1 they presented them with *prime* words in L2 and targets in L1 and in study 2 they reversed the order. In both cases, the targets were compound words (i.e., words that integrate two single words, such as midday), while the primes were: correct translations of the compound word (e.g., midday), parts of the translated word (e.g., day), or unrelated words (e.g., work). The results indicated that three components were involved in this process. On the one hand, for both study 1 (L2-L1 direction) and study 2 (L1-L2 direction), the unrelated words presented a higher N400 than the other conditions. On the other hand, the words of study 2 presented effects in earlier temporal windows: specifically, the N150 component was decreased in the unrelated words with respect to the other two types. In addition, the N400 component was observed to be decreased for the related components compared to the translated words. This asymmetry in translation effects is interpreted as a facilitation by the L1 for the morphological decomposition of compound words in the L2, present from the earliest moments of word recognition.

However, the modulation of N400 differs when the priming paradigm is not present. When participants are asked to indicate whether the second word presented in a task is an appropriate translation of its antecedent (e.g., for table, an appropriate translation would be mesa and not tabla), the direction in which the translation is made has significant effects on N400. Palmer et al.[50] conducted two studies, in which bilingual participants were asked to indicate whether a pair of words in L1 and L2 shared meaning. In both cases, the authors found that reverse translation (L2 to L1 direction) produced greater negativity in N400 than direct translation (L1 to L2 direction). Similar results were found in Chen et al.[45] According to these authors, the asymmetry in the L1 and L2 domain conditions the access to meaning in L2, since only the prior presentation of the stimulus in L1 allows a preparation to provide a correct response in L2.

Also, similarity between words (i.e., the features and meanings they share) produces effects at the electrophysiological level. Guo et al.[51] examined the time course of words similar in form or meaning using two studies. Broadly, both consisted of asking participants to indicate whether a word in L2 (target) was the correct translation of another (prime), previously presented in L1. The critical conditions were incorrect translations, which could belong to two conditions: distractor words related by form or by semantics to the L1 word. For example, *prime* latent, whose correct translation is latent, was paired with a synonym of latent, such as latiente (distractor by form), while *prime* man, whose correct translation is hombre, was paired with mujer (distractor by semantics). These pairs were compared with control pairs consisting of the same *prime* stimulus (latent and man, in the previous examples) paired with an unrelated target word. In a first study, the authors used a long interval period between the stimulus in L1 and L2; in the second, a short interval. They found that semantic pairs elicited a lower N400 for both time intervals compared to unrelated pairs. In contrast, only the short interval elicited a higher LPC. Form pairs, on the other hand, presented significant modulations in the longer intervals: in both the earliest and the latest component, distractor pairs elicited lower N400 and higher positivity in LPC than controls. For the authors, semantic information would be prioritized in the processing of bilinguals, as it would facilitate processing, as evidenced by the decrease in N400 when compared to controls, even in short time intervals between *prime* and target. In the case of form-related information, where access to meaning is not directly related, only longer inter-stimulus intervals facilitate integration between *prime* and target. The effects observed in N400 would indicate that the presence of L1 activates the translation equivalents in L2 and prepares the person for the response. This process would be faster in the case of semantically related words, and more elaborate in the case of words similar in form. In turn, the capacity for later reanalysis, marked by the increase in LPC, would depend on early effects in N400.

Moldovan et al.[52] performed the same task as Guo et al.,[51] but manipulated the degrees of semantic similarity during the translation process. For each target word, stimuli with high relatedness or similarity (AR; *donkey - horse*), low relatedness

Table 3. Translation studies on ERP response.

Reference	Sample&	Design/Task	Comparison	Component	Analysis windows	Results
(49)	BS	Masked priming	Composite vs. Component vs. Not related Translations.	N150	100 - 200 ms	St. 1: No differences
	(N=20)	St. 1: Direction L2 - L1.				St. 2: composite translation > not related
		St. 2: Direction L1 - L2.				St. 2: related component > not related
				N250	200 - 300 ms	St. 1: No differences
						St. 2: related component < compound translation
				N400	350 - 500 ms	St. 1: not related component > composite translation
						St. 1: not related component > related component
						St. 2: related component > composite translation
						St. 2: not related component > composite translation
						St. 2: not related component > related component
(50)	St. 1: BS (N=17)	Translation recognition	Translation: direct vs. inverse	N400	300 - 500 ms	St. 1. Inverse > Direct
			Concreteness: concrete vs. abstract			St. 1. Concrete = Abstract
	St. 2: BS (N=20)					St. 2: Inverse > Direct
						St. 2: Concrete = Abstract
(12)	BS	Translation recognition	Traducción: directa vs inversa	N400	300 - 450 ms	Inverse > Direct
			Familiar vs. non-familiar			Familiar vs. non-familiar
	(N=21)					Translation x familiarity: inverse > direct only for familiar words
(51)	St. 1: BS SOA-L	Translation recognition	Translation pairs: translation vs. distractors	P200	150 - 300 ms	St. 1: Semantic pairs: unrelated > related
			Semantic pairs: related vs. unrelated			St. 1: Translation pairs: translations > controls
	Est. 2: BL SOA-C					St. 2: Semantic pairs: no differences
						St. 2: Translation pairs: no differences
				N400	300 - 500 ms	St. 1: Semantic pairs: no differences
						St. 1: Translation pairs: no differences
						St. 2: Semantic pairs: not related > related
						St. 2: Translation pairs: no difference
				LPC	500 - 700 ms	St. 1: Semantic pairs: not related > related
						St. 1: Translation pairs: translations > controls
						St. 2: Semantic pairs: not related > related
						St. 2: Translation pairs: translation > distractors
(52)	BS	Masked priming	Highly Related Word Pairs (HR): Related and not related	P200	150 - 300 ms	HR : No differences
	(N=24)					LR : No differences
			Low Related Word Pairs (LR): Related and not related			TN: No differences
				N400	300 - 500 ms	HR : Not related > Related
			Translation Neighbors (TN): Related vs. not related			LR : Not related > Related
						TN: No differences
						HR > LR
				LPC	500 - 700 ms	HR: No differences
						LR: No differences
						TN: Not related > Neighbors
						TN: Related > Not related
(53)	Students L2 SOA - L	Translation recognition	Semantic pairs: distractors vs. control	P200	150 - 300 ms	SOA - L: distractors (semantic and translation) > control
	(N=34)		Translation pairs: distractors vs. control			SOA - C: No differences
				N400	300 - 500 ms	Semantic distractors < Control in both SOAs
	Students L2 SOA - C			LPC	500 - 700 ms	SOA - L: distractors (semantic and translation) > control
	(N=35)					SOA - C: No differences

Nota. BS: bilingual sample; MS: monolingual sample; L1: first language/dominant language; L2: second language; LDT: lexical decision task; AS: number of associated senses; LF: low frequency; HF: high frequency; LPC: late positive component/complex; EPN: early posterior negativity; SOA: Stimulus onset asynchrony or similarity (BR; *donkey - bear*) or translation neighbors (i.e., words morphologically similar to the correct translation; *man - hungry*) were alternated. The authors found that both AR and BR pairs modulated the N400 component, such that unrelated pairs presented greater amplitude than related pairs. This effect was greater for AR than BR. On the other hand, translation neighbors exhibited modulation of the LPC component, such that related translation neighbors exhibited lower amplitudes than unrelated ones. These differences indicate that the degree of semantic similarity facilitates the way in which content is accessed to correctly recognize a word in L2. In turn, the presence of the LPC component in translation neighbors would show the cognitive efforts involved in conflict resolution: one hypothesis is that the presentation of the L1 would automatically trigger the correct translation in L2 and the morphological similarity of the translation neighbors would demand a reanalysis of the presented L2 word.

Similarly, Ma et al.[53] evaluated native English speakers learning Spanish as L2. The authors followed a similar protocol as Guo et al.,[51] however, they explicitly compared two groups of participants on the same tasks (Group 1: long interval, Group 2: short interval). In addition, they performed the same manipulations on the target words as Guo et al.[51] The authors found that the P200 component was found to be involved only in the longer time intervals, indicating that the distractor words showed greater positivity than their corresponding controls. In the case of the N400 component only the semantic distractors showed lower negativity than the control words. As in the study by Guo et al,[51] the modulation of P200 was interpreted as a priming triggered by the presence of a word in L1, which allowed priming of the translation equivalent at longer times. In contrast, the effects in N400 unique to semantic distractors and present in both types of intervals suggest that semantic relation effects appear faster and more effective than translation relations.

In summary, the results for translation processes would depend primarily on the task presented and the type of translations requested. For example, direct translation (L1 to L2) facilitates word recognition as it activates L1 representations before L2 ones, which show a faster and more efficient access. In this sense, the study of translation integrates processes of morphological decomposition, semantic identification and word type.

Regarding the ERP components involved, two studies included the analysis of early components, identified as negativities or positivities in the first 300 ms after stimulus presentation: N/P150, P200 and/or N250. In all cases they are identified as physiological indicators of the location of attentional resources. On the other hand, three studies also analyzed the LPC component. Only two of the collected studies examined just the N400 component.

Discussion

Considering the conditions offered by the ERP technique for the recording of cognitive processing occurring in reduced periods of time, the aim of the present scoping review was to describe a set of experimental investigations examining the processing of lexical items in bilingual individuals by analyzing changes in electrophysiological responses. Overall, the findings outlined two major lines of research in the area: on the one hand, the impact of various psycholinguistic factors on word recognition, including sub-lexical factors such as morphology and lexical factors such as emotional processing and semantic richness, and, on the other hand, cases of translation.

From the analyzed articles it can be highlighted that the methodology in the analysis of electrophysiological material for word recognition follows a systematic pattern: a first component, which would indicate attentional foci at the earliest time (approximately $<$ 300 ms after the presentation of the target stimulus); secondly, a lexical recognition component, located between 300 and 600 ms after stimulus presentation, commonly identified as N400; and, finally, a component identified with the tasks of reanalysis of the information and the presented response, located at $>$ 600 ms after stimulus presentation. Figure 3 illustrates these processes. While the functional characteristics are largely defined, the temporal characteristics differ between each investigation. In particular, while there seems to be a greater consensus regarding the temporal components, at least from the nomenclature (N400, e.g., for Lehtonen[31], among others), no consensus is observed regarding the polarity or temporal boundaries of the early components. In contrast, the functional interpretation of these components (repositioning of attentional resources for stimulus recognition) remains stable throughout the research. These discrepancies could be attributed to experimental manipulation, which could trigger electrophysiological responses at different times of processing.

Each area of research circumscribed in the present review showed particular results. First, certain sub-lexical factors, such as morphology, and lexical factors, such as semantic content, favor word recognition throughout second language learning. The participation of fully bilingual samples and L2

learners is noteworthy. The electrophysiological results indicate that bilinguals use cognitive resources in an alternative way to monolinguals, as evidenced by a facilitation in morphological decomposition.[31] In contrast, at the semantic level, the components involved vary according to the presence or absence of emotional content. For this type of words, the time course is mainly defined by the joint presence of two components: EPN and LPC. Unlike other levels of analysis, such as morphological, this level includes as a condition the analysis after 300 ms and of later components.
However, some authors[47] also indicate the use of N400 in this type of studies when combined with priming tasks.

Translation, in second place, integrates all the components used in the previous levels. Although no research included in this paper used emotional stimuli for translation tasks, the general pattern of using ERP components is similar: early analysis components are taken into account as indicators of attentional capture, while the N400 component functions as an indicator of the semantic relationship between words in L1/L2 and their corresponding translations.[51-53] The ERP study in this area allows us to identify that back translation (from L2 to L1) requires more cognitive effort than direct translation. This is observed in the extensions of the N400 component, since the activation of words in L2 does not trigger L1 representations as effectively. These effects are similar to those shown for pseudoword recognition.[51]

This work focused on the identification of ERP components involved in visual word recognition in bilingual populations. It should be noted that this review presents a few limitations that should be taken into account. Although the research methodology of the reported studies was based on visual tasks (reading or visual recognition), the phonological level has also been studied with the technique of evoked potentials.[55-57] How this level interacts with such stimulus presentation is beyond the scope of the present work, however, it has been observed that phonological markers, such as orthographic similarity used in repetition priming by Liang and Chen[32] (plant-plan), also interact in visual processing. Future research could identify the presence and behavior of these factors in word recognition under the oral modality to obtain a comprehensive approach to this issue.

On the other hand, the information extracted from EEG has higher temporal than spatial resolution.[6,7,15] Numerous studies also include analyses of varying spatial extent: from interhemispheric comparisons to single electrode analyses. In this work, some research[26] incorporated this type of analysis.
However, due to the absence and even lack of consistency across studies to define this information, such results were not addressed. Further research could define the systematicity and consistency of this information.

The learning and use of other languages, known as bilingualism, is a widespread phenomenon, both in developed and undeveloped countries and in various socioeconomic strata.[1] Due to this worldwide prevalence, the benefits of bilingualism have become a topic of study in the cognitive sciences. This paper summarizes the results of research that focused on the basic processes underlying the different areas of study presented above. In general terms, the results are consistent, although certain aspects of the methodology and analysis still require more specificity. In summary, the results presented allow us to identify those physiological indicators involved in the activity of speakers that could be applied in the clinical study of different neuropsychological conditions, such as bilingual aphasias.

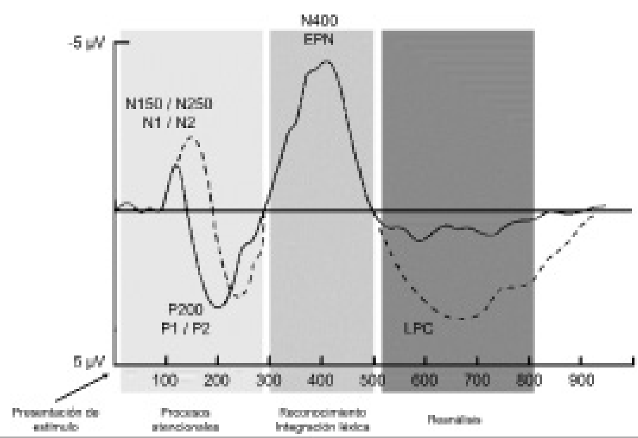

Figura 3. Idealized diagram of ERP components involved in word recognition. Legend: LPC: late positive component/complex; EPN: early posterior negativity. Adapted from Ma et al.[53]

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