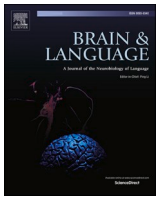
Brain & Language 268 (2025) 105614



Contents lists available at ScienceDirect

Brain and Language

journal homepage: www.elsevier.com/locate/b&l





Six advances in research on bilingualism☆

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ARTICLE INFO

Keywords:
Bilingualism
AI
Psycholinguistics
Emergentism
Identity
Lifespan

ABSTRACT

In the 30 years since the publication of Cognitive Processing in Bilinguals (Harris, 1992), the study of cognitive processing in bilingual speakers has branched out in several new directions. Each of these new directions has involved advances in theories, conceptualizations, methods, and findings. The six new directions we will highlight are these:

1. The shift from a focus on experiments with word lists to a focus on utterances,
2. Relating models of human performance to Artificial Intelligence (AI) models,
3. Understanding patterns of bilingual development across the lifespan,
4. The effects of cross-language transfer,
5. The shaping of bilingual cognition and age effects through social and motivational forces, and.
6. New methods for *in vivo* online tracking of language learning.

1. Introduction

Due to space limitations, we cannot review the major advances that have occurred in understanding the neurolinguistics of bilingualism (Morgan-Short & van Hell, 2023). This is indeed the seventh major new development in our field. Fortunately, the contributions from that perspective are discussed in other chapters in this special issue. Together, the six new directions we will review, along with work in neurolinguistics, provide us with a richer understanding of the many complex dimensions of bilingualism. Emergentist theory allows us to integrate this complexity into a coherent framework. In fact, without these advances, an adequate articulation of emergentist theory for multilingualism would not be possible.

2. From word lists to utterances

One major advance in our understanding of bilingualism arises from the shift away from models that rely on experiments with lists of single words to models based on the dynamic construction of whole utterances. Over half of the chapters in the Harris collection relied on lists of words to test theories regarding recognition, memory, and production at the word level. Such studies were designed to evaluate the extent to which bilingual memory and processing rely on a conceptual store in which languages are either separate or integrated. The approach to this issue from the 1950s contrasted coordinate bilingualism in which the two languages have separate stores vs. compound bilingualism in which the stores are integrated. The approach of the 1980s contrasted selective (one language) access vs. non-selective (multiple languages) access. However, the issue of separation vs. integration of storage and access remained the same. Often, studies in this word list tradition found non-selective activation, although the specific nature of the experimental task and materials was found to impact the extent of non-selectivity (Durgunoglu & Roediger, 1987; Kirsner, 1986). The problem with this emphasis on single word retrieval is that reports of non-selectivity from word list experiments (Beauvillain, 1992) may not reflect actual language processing. An alternative conceptualization holds that, when using a given language in full utterances, the forms of that language co-activate each other, minimizing (but not fully obviating) the effects of the non-selectivity found in the word list experiments. There are several supports for this interpretation.

First, research on brain function over the last four decades has highlighted the extent to which the activation of meanings, concepts,

☆ This article is part of a special issue entitled: 'Bilingual Processing (YBRLN)' published in Brain and Language.

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https://doi.org/10.1016/j.bandl.2025.105614
Received 3 February 2025; Received in revised form 15 March 2025; Accepted 2 July 2025
Available online 9 July 2025
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words, phrases, and sounds depends on co-activation of inputs that are gated by attentional processes (Nassar, Helmers, & Frank, 2018). In the drift diffusion model (Ratcliff, Van Zandt, & McKoon, 1999), gating occurs through a thresholding mechanism that depends on cue strength summation, as in the Competition Model (MacWhinney, 1989, 1992, 2021) and other connectionist approaches. This competitive process serves to suppress forms in the language not currently in use while producing or comprehending an utterance. Moreover, because words in one language have strong connections to other words in the same language, activation can spread across many related forms in that language. Although words are also connected to their translation equivalents in other languages, this activation is less than that achieved by the wider and reciprocal spread of within-language activation (Hernandez, Li, & MacWhinney, 2005).

Further insights into this process come from data on hub-and-spoke activation (Patterson & Ralph, 2016) for the conceptual and embodied grounding of words and concepts. For example, the "hub" representation of a word like *hammer* in the anterior temporal lobe (Kemmerer, 2015) receives inputs from the "spoke" areas that process the visual, manual, auditory, and tactile features of a hammer. This view of featural support from diverse cortical areas for word activation is in line with de Groot's (2014) emphasis on the role of microfeatures in lexical activation and the fact that these microfeatures may differ in detail between languages. Thus, although translation equivalents may share many features, they can also differ in specific regards. As MacWhinney (1992) noted, this is also true for grammatical categories which may be only partial similar between languages.

Cognitive psychologists have also expressed dissatisfaction with the use of word lists to study the organization of memory. For example, Hintzman (2011), p. 253 criticizes studies based on the use of the methods of paired associates, free recall, and recognition memory because they relate "only weakly to subjective experience, do not clearly differentiate between structure and strategy and are oriented more toward remembering which words were in a list than to the diverse functions that memory serves." He argues that the evolutionary purpose of memory is to construct a spatiotemporal model of the environment through the process of reminding, and that research should focus on the study of this process in real-life environments.

The contribution to this special issue from Zhao et al. (2025) highlights another way in which the shift from a focus on word lists to a focus on whole utterances has been enriching the study of bilingualism. This work extends the visual world framework (Allopenna, Magnuson, & Tanenhaus, 1998) by requiring participants to keep in mind the image called up by an utterance. Then they are given a display with a matching and a mismatching image and asked to select the one that aligns best with their mental model. In general, native speakers do this more quickly and accurately than L2 learners, although the most advanced learners begin to approach native speaker levels. Following earlier suggestions in MacWhinney (2018), the authors refer to this modification of mental model construction needed for fluent use of L2 as functional restructuring. This is surely an important component of L2 learning and cognitive processing in bilingualism. Beyond these important results, this research has shown that when L1 and L2 misalign in their expectations for an image, judgments are slower and depend more on the structure of L1. These results point to an extension of Slobin's interpretation of linguistic relativity as "thinking for speaking" (Slobin, 1988) and suggest that there is also an L1 effect of "thinking for comprehending".

3. Lessons from AI

The critique of the word-list approach to bilingualism receives further support from the results of new systems based on machine learning (ML) and Artificial Intelligence (AI). Breakthroughs in automatic speech recognition (ASR), language translation, and generative AI have shown that, given sufficiently powerful computers, an abundance of training data, methods for processing complete texts in context, and clever use of hardware, computers can master many features of human language. Using this linguistic base and further training in the steps of logical problem analysis, models like DeepSeek (Guo et al., 2025) can produce well-reasoned analyses of complex problems in logic, math, and system design. Moreover, large language models (LLMs) can outperform linguistic theories in terms of predicting exact patterns in psycholinguistic studies (Ambridge & Blything, 2024).

The methods these systems use to do this only partially resemble those used by humans, but the resemblances are instructive and suggestive of ways to think about language learning, bilingualism, and mental model construction. The first parallel with human learning and processing is reliance on previous context and learning to predict the next word in fluent speech (Elman, 1998; Kuperberg & Jaeger, 2016).

In both humans and AI systems, prediction is most accurate when information derives from both within and across utterances. This points to a second similarity between AI systems and humans regarding methods for storing and using context. For both machines and learners, computing information from within the utterance is relatively easier than computing information from elsewhere in the context. However, as AI systems like DeepSeek manage to bring in a wider range of context, their performance improves. Similarly, young children are heavily focused on the here-and-now (Clark, 2015) using only information from the immediate present. However, through learning they manage to bring in additional context. Older second language learners and advanced bilinguals have the advantage of already knowing how to bring in information from a wider context. Although short-term memory limitations can constrain the use of such wider spoken context, improved fluency can facilitate this process and the same is true for AI systems. Currently, AI systems use previous context directly at the point of processing of the incoming next word. Some accounts suggest that this is the basic mechanism used by humans (Schrimpf et al., 2021). However, psycholinguistic research (MacWhinney, 2008; Pecher & Zwaan, 2005) indicates that human processing involves not just prediction, but rather integration of incoming information into a full mental model. This level of integration has important consequences for our understanding of bilingualism (Zhao et al., 2025) and for future improvements to AI systems.

A third similarity between AI systems and the brain is that processing relies on extraction of information into a huge number of parameters and multiple layers or levels (MacWhinney, 2015) of processing in models such as ChatGPT (Vaswani et al., 2017). In the human brain, storage also relies on the enormous number of synapses (Cantlon & Piantadosi, 2024) as well as clever ways in which the hippocampus works to avoid catastrophic interference (Valiant, 2012). AI systems have not yet imitated all these neuronal methods from humans, but as they do their performance improves.

A fourth similarity is that both AI systems and humans learn based on error and exploration. Early AI deep neural network (DNN) systems relied on generalizations of the back propagation algorithm (LeCun, Bengio, & Hinton, 2015) to train across multiple layers. Humans also use error propagation across the network and levels to extract first general expectations and then exact predictions. However, rather than relying only on back propagation, humans make extensive use of exploration and reinforcement (Lee, Seo, & Jung, 2012) of successful attempts and inhibition of erroneous attempts. What is crucial about this type of learning is that the goal state must be clearly kept in mind and both successes and failures are recorded. This process is quite fundamental to language learning during which learners make continual mistakes but get closer and closer to the target language. Jespersen (1922, p. 143) cites the Slavonic proverb that "If you wish to talk well, you must murder the language first." AI systems, such as DeepSeek (Liu et al., 2024), also implement a similar reinforcement learning approach.

The four mechanisms of prediction, context encoding, large parameters and levels, and reinforcement learning each have their counterparts in human language learning, although the details are extremely

different. What is interesting is the degree to which the organization of memory in both humans and AI systems produces emergent categories, such as semantic fields for foods, syntactic categories such as direct object, and morphological features such as number or gender and constructional patterns. The process of extraction of these features and patterns is particularly relevant to issues of transfer and learning in bilingualism. Given the number of parameters and levels in these models, tracking details of these emergent categories is difficult. However, several studies (Greenacre, Defina, Akbar, & Garcia, 2024; Manning, Clark, Hewitt, Khandelwal, & Levy, 2020; Nandi et al., 2024; Shain, Blank, van Schijndel, Schuler, & Fedorenko, 2020) show that the models are using emergent categories to structure their processing. To illustrate how this can work, consider the role of gender in structuring the German noun system into three genders – masculine, feminine, and neuter. Gender-marking forms such as adjectives, articles, and possessives all come right before the noun. This allows the listener to predict the gender of the following noun based on that cue. Processing can then take advantage of local reciprocal connections and shared phonological and semantic features within each gender category group (Köpcke, 1996). For early simultaneous bilinguals, these structures can be learned for each language separately. However, for successive bilinguals transfer and entrenchment can make it more difficult to achieve organization based directly on these cues (Li, Farkas, & MacWhinney, 2004).

4. Developmental patterns

To fully understand multilingualism, we need to trace through the ways in which child and adult learners master multiple languages (Grainger, Midgley, & Holcomb, 2010). To evaluate the extent to which a bilingual child's languages are separate or interacting, we need to have well-sampled corpora that can track phonological, lexical, and grammatical learning across time. The premiere example of work of this type is the corpus from nine Cantonese-English bilingual children in CHILDES (https://childes.talkbank.org) constructed by Yip and Matthews. Their detailed analyses reveal patterns of between language influences and differential use of languages across contexts (Yip & Matthews, 2000). Given the vast variety of language combinations and social configurations involved with childhood bilingualism, we need still more corpora of this type to understand the possible configurations and progression of childhood bilingualism. For the study of later bilingual acquisition, we can turn to corpora in SLABank (https://slabank.talkbank.org) such as LANGSNAP or FLLOC for Anglophone learning of French and Spanish (McManus, Mitchell, & Tracy-Ventura, 2021).

Childhood bilingualism also presents a major challenge in terms of patterns of language attrition. International adoptees who arrive in the new country before age 8 undergo a complete loss of their first language, whereas children who arrive at an older age maintain their first language to some degree (MacWhinney, 2019). Studies such as Choi et al. (2017) have compared adolescent native speakers with early adoptees and shown better relearning of a few phonological distinctions of first language (L1) in the adoptees, but what seems like relearning may only reflect adoptees' increased motivation for building ties with their L1 culture.

It is difficult to reconcile this pattern of complete attrition of a well-learned L1 with the idea that linguistic forms undergo progressive entrenchment during development (Brooks & Tomasello, 1999; Zevin, 2012). Surely, by the age of 5 or 6, a child's L1 would be sufficiently entrenched to avoid attrition. One possibility is that the type of entrenchment involved during later childhood is more extreme than the basic usage-based entrenchment involved earlier on. Perhaps there is a *meta*-entrenchment that takes effect at around age 8 and works to block facile second language (L2) learning and also to preserve L1 (Montrul & Yoon, 2019). One possible account attributes the greater resistance to L1 attrition in older children to what Karmiloff-Smith (1979) has called representational redescription. According to that account, the solidification of L1 against attrition that occurs in older children results from a rise of metalinguistic awareness, including literacy and an awareness of bilingualism, as foreshadowed in the chapter by Arnberg and Arnberg (1992) in Harris (1992).

5. Transfer

One major stream of research on bilingualism focuses on examination of the final state of bilingualism. A contrasting focus examines how L2 learners reach this state, especially for sequential bilingual speakers. Within this area, a core issue is the role of cross-linguistic transfer. In the Harris collection, MacWhinney (1992) focused on L1-to-L2 transfer, and posited that massive simple L1 transfer occurred at the initial stage of L2 learning, followed by a large amount of L2 reconstruction during later L2 learning. Specifically, the claim was that L2 learners try to transfer as much as they can from their L1s to facilitate L2 learning. If their L1s are different from their L2s, they need to deal with negative transfer, and consequently, their L1 knowledge hinders their L2 learning. If their L1s lack relevant structures or patterns and positive transfer becomes impossible, they will need to reconstruct L2 from the ground up.

Although positive transfer occurs wherever possible, it is not immediate. As Hartsuiker et al. (2004) and MacWhinney (2012) note, transfer can initially be conservative and item-based and only becomes general once confirmed. Moreover, learners will quickly transfer matching unmarked patterns but delay on transfer of matching marked patterns. For example, as Pienemann et al. (2005) noted, Swedish learners of German prefer to transfer to German the unmarked Swedish word order that places the subject before the tense marker in the German equivalent of sentences such as *Peter likes milk today*. Although Swedish has a pattern that allows the order *Today likes Peter milk*, learners tend not to transfer this pattern initially, because it is the more marked alternative. Bernolet et al. (2013) report a similar pattern when measuring syntactic priming between Dutch and English genitive constructions.

An example of a complex pattern of positive transfer, negative transfer, and learning without transfer comes from a study by Gao, Wiener and MacWhinney (2022) on L2 learning of Chinese verb separation, a language-specific grammatical process with seven different variants through which bimorphemic compounds are separated and expanded into phrases. The authors found that reconstructing Chinese verb separation by attempting to transfer from L1-European languages was so challenging that they were far from mastering the separation patterns even once they had reached an advanced level.

In the area of lexical learning, positive transfer from L1 to L2 is massive, as reflected in superior adult learning in this domain (Snow & Hoefnagel-Hohle, 1978). This is because the meanings underlying translation equivalents are generally so close in different languages, despite interesting differences in shades of meaning and reference (de Groot, 2014). An example of this effect is the cross-linguistic transfer of cognates. Hancin-Bhatt and Nagy (2015) found that bilingual children in Grades 4 through 8 demonstrated an increased ability to translate cognates between two languages as they aged. Their study also showed that the children had more knowledge of the cognates compared to the general vocabulary of both languages.

Ben-Yehudah, Hirshorn, Simcox, Perfetti and Fiez (2019) provided an example of negative transfer based on the nature of the writing system. The Chinese writing system is non-alphabetic and combines semantic and phonological radicals into complex characters. Korean and English, on the other hand, are both alphabetic and analytic. The authors found that Chinese-English bilinguals processed irregular English words like *yacht* holistically, whereas Korean-English bilinguals decoded them analytically. The Chinese-English bilinguals showed slower naming speed in the experiment, indicating a negative effect of the lack of an ability to decode English words analytically.

Kroll and Dussias (2024) view cross-linguistic transfer as a continuously active and evolving system in which transfer is bidirectional and permeates across various proficiency levels. Cross-linguistic activation

involves constant competition because the two languages of the bilingual speakers are at least partially constantly active. However, speakers acquire real-time regulatory and adjustment skills to resolve these competitions. In this regard, Bialystok (2024, 2025) has identified attention allocation as a key skill necessary for navigating the two activated languages. In support of this view, Verbeek et al. (2022) evaluated the impact of attentional control on Turkish–Dutch bilingual children's perception and production of their L1 and L2 speech sounds. They revealed an effect of interaction between attentional control and cross-linguistic transfer. For shared phonemes that facilitated positive L1-to-L2 transfer, attentional control only influenced production. Moreover, for the phonemes differing between L1 and L2, which resulted in negative transfer, attentional control displayed effects on both production and perception. Overall, our increasing understanding of transfer effects provides useful information for the fuller articulation of an emergentist account of bilingualism based on competition, levels, timescales, mechanisms, and constraints.

6. Age Effects, Identity, and Motivation

There was virtually no mention in the Harris book of the role of critical periods in bilingualism. Perhaps this was due to the widespread acceptance at that time of Lenneberg's (1967) claim that the completion of lateralization and myelinization around age 13 marked the end of the ability to acquire a second language (L2) to native speaker levels. However, more recently, evidence in support of this position has been questioned from a variety of directions.

For example, Werker and Hensch (2014) show how a complex system of GABA-sensitive circuitry and neurotransmitters can control the loss of neural plasticity in surgically induced amblyopia in cats. Moreover, the distribution of this GABA-sensitive circuitry varies across brain areas and the closure of the sensitive period can be reversed through attention-based neuromodulators. Based on these findings, Werker and Hensch (2014) propose a model of cascading sensitive periods across various levels of language learning. Their treatment of differential age effects across diverse linguistic levels is consistent with emergentist accounts that emphasize the variable role of constraints across structural levels (Caldwell-Harris & MacWhinney, 2023) during development.

A second line of questioning of critical period theory is reflected in Flege's Revised Speech Learning Model (SLM-r) (Flege & Bohn, 2021). This model attributes age-related effects in L2 phonological learning to variations in language input. Specifically, Flege reinterprets his earlier findings regarding critical periods for English-Italian immigrants in Ottawa as reflecting the impact of ongoing exposure to Italian, rather than the closing of a critical period. He notes that much of the variation in articulation in this population can be attributed to social factors such as the nature of the use of English in schools and the workplace. Caldwell-Harris and MacWhinney (2023) extend this analysis across six developmental periods, emphasizing the extent to which the toddlers receive large amounts of "comprehensible input" and continual social and emotional support without interference from the many responsibilities and L1 commitments that adults must face.

A third line of questioning of critical period theory is a mathematical model called Energy Conservation Theory (ECT) provided by Han and Bao (2023) to account for age-related changes in the success of L2 learning. The five parameters in the model are input, motivation, aptitude, L1-L2 distance, and developmental stage. The model shows how the learner's initial high level of motivation soon bumps into barriers such as L1-L2 distance which function as a centrifugal force leading to incomplete asymptotic acquisition. It is further assumed that weaker entrenchment of L1 and greater neural plasticity in child learners makes L1-L2 distance less of a barrier to learning, producing a higher asymptotic result. Caldwell-Harris and MacWhinney (2023) take this motivational account further by emphasizing the extent to which children focus on intentionally (Bloom & Tinker, 2001) advancing their own personal agenda for preference management (Karniol, 2010) in language learning. As children mature, they enter social, ethnic, and national groups that further shape motivations to learn or use a given language. These forces include identity formation, group membership, role expectations, and possible discrimination.

Extending this analysis, the last line of questioning of critical period theory focuses on the central role of identity in shaping bilingual speakers' usage of their languages. In his chapter for the Harris volume, Grosjean (1992) argued that bilingual speakers are complete entities and that they should not be studied as two monolinguals in one person. While monolinguals use one language to complete various communicative tasks, bilinguals use their two languages. Thus, he proposed a spectrum of speech modes for bilingual speakers: a monolingual mode at one end, where the bilinguals perform as monolinguals, maintaining one language active while trying to suppress the other one; and a bilingual mode at the other end, where the bilinguals choose a base language according to many factors such as interlocutors, context, and communication goals and embed words or phrases of the other language frequently. Kroll and Dussias (2024) extend this account by analyzing how language competition and regulation are revealed in the process of code-switching. In a related formulation, Titone and Tiv (2022, 2023) have called for psycholinguistic and neurolinguistic investigations of social factors on bilingual learning and development. They review their experimental studies comparing bilingual speakers' social network with those of monolingual speakers, offering empirical evidence that bilingualism influences social identity. Together, these new findings regarding age-related effects and mechanisms provide crucial data for an emergentist account of the development of bilingualism.

7. New methods

The approaches mentioned above emphasize the role of social and motivational forces across the lifespan as determining patterns of bilingual development. To test and quantify the role of these forces and others, we need detailed data on actual patterns of language exposure and use. Traditionally, data of this type has been gathered using language history questionnaires (Li, Zhang, Tsai, & Puls, 2014) or proficiency measures such as LexTALE (Lemhofer & Broersma, 2012). However, it is difficult to determine the reliability and validity of these methods as measures of actual language exposure and use. The widespread adoption of mobile phone technology (iPhone, Android, etc.) now makes it possible to implement ESM (experience sampling method) to track *in vivo* language encounters in detail (Flege & Wayland, 2019). For example, it has been found that study abroad often fails to obtain L2 learning improvements beyond traditional study at home (Freed, 1998). One possibility is that students in these programs are not making use of L2 more than a few hours each week. However, to determine this accurately, we need to query the learners on their cellphones about their current language use according to a predetermined sampling schedule. These queries could even track further features such as topics discussed and problems with language usage.

A different way of tracking L2 development across time is to track students' progress in online (i.e. web-based) learning systems. One example of such a system is Duolingo, a proprietary system for L2 learning that includes basic language exercises, vocabulary learning, translation exercises, and pronunciation checks across successively more advanced levels of L2 learning. Because the Duolingo system tracks individual student responses, it can create learner models using item analysis (item response theory, IRT) and machine learning methods. Furthermore, the effects of changes in the structure or processes of the system can be controlled experimentally. Using this approach, Duolingo was able to validate the important role of expanded interval recall (Kang, Lindsey, Mozer, & Pashler, 2014) to construct their BirdBrain model (Bicknell, Brust, & Settles, 2023). It is possible to use this approach to target the learning of specific linguistic constructs in a maximally analytic way, as in the PinyinTutor (Kowalski, Zhang, & MacWhinney, 2014) which allows learners of Mandarin and Cantonese

to improve their recognition of Chinese phonological contrasts by listening to words and writing them out in Pinyin. Using the data collected from thousands of users of this system, Kowalski et al. (2014) were able to evaluate the nature of difficulties in recognition for specific Mandarin tones and segmental phonemes for learners with L1 English, Japanese, and Cantonese. In addition, through analyzing the data of the participants from various levels of Mandarin proficiency, they were able to depict the developmental trajectory of L2 Mandarin phonology. MacWhinney (2017) explains how the extension of methods such as these can provide a much richer picture of L2 learning.

8. The emergentist framework

To piece together the new information about bilingualism that we will be deriving from these six sources, we need a framework that can allow us to understand the relations between the various processes, structures, and developments involved in bilingualism. For this, we can turn to the framework of emergentism (MacWhinney, 2015) which integrates the contributions of many well-supported and detailed theories regarding the neural land social mechanisms and constraints that govern competition between linguistic forms, levels of structural organization, and timescales of language development and change. To illustrate the value of an emergentist approach to bilingualism we could consider ways of understanding cross-language competition and transfer, as emphasized by Kroll and Dussias (2024). For example, looking at how competition impacts transfer, we can see a role for mechanisms and constraints such as gating, cognate status, markedness, frequency, embodied imagery, functional restructuring, dynamic systems effects, and a variety of social inputs such as identity expression, preference management, and group solidarity. Looking at how transfer operates across linguistic levels, we can see marked divergences in processes, mechanisms, and constraints between the articulatory, auditory, lexicon, morphological, syntactic, mental model, and discourse/pragmatic levels (Caldwell-Harris & MacWhinney, 2023). For sequential bilinguals, the emergence of structures on each of these levels is largely scaffolded by their prior emergence in L1. For simultaneous bilinguals, these levels emerge together through development. Finally, when we look at the role of timescales on transfer in bilinguals we begin to consider the important impact of lifespan changes, cohort effects, peer group formation, workplace demands, and immigration, as described by Caldwell-Harris and MacWhinney (2023). By deriving further detailed information from the six research lines we have highlighted in this paper, along with work on the neurolinguistics of bilingualism, we will have the type of data needed to properly articulate an emergentist framework for understanding processing, structure, and usage in multilingualism.

CRediT authorship contribution statement

Brian MacWhinney: Writing – review & editing, Methodology, Writing – original draft, Conceptualization. **Zhe Gao:** Writing – original draft, Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the time course of spoken word recognition using eye movements: Evidence for continuous mapping models. *Journal of Memory and Language, 38*(4), 419–439. https://doi.org/10.1006/jmla.1997.2558

Ambridge, B., & Blything, L. (2024). Large language models are better than theoretical linguists at theoretical linguistics. *Theoret. Linguist., 50*(1–2), 33–48.

Arnberg, L. N., & Arnberg, P. W. (1992). Language awareness and language separation in the young bilingual child. In *Advances in psychology* (pp. 475–500). Elsevier.

Beauvillain, C. (1992). Orthographic and lexical constraints in bilingual word recognition. In *Advances in psychology* (pp. 221–235). Elsevier.

Ben-Yehudah, G., Hirshorn, E. A., Simcox, T., Perfetti, C. A., & Fiez, J. A. (2019). Chinese-English bilinguals transfer L1 lexical reading procedures and holistic orthographic coding to L2 English. *Journal of Neurolinguistics, 50*, 136–148. https://doi.org/10.1016/j.jneuroling.2018.01.002

Bernolet, S., Hartsuiker, R. J., & Pickering, M. J. (2013). From language-specific to shared syntactic representations: The influence of second language proficiency on syntactic sharing in bilinguals. *Cognition, 127*(3), 287–306. https://doi.org/10.1016/j.cognition.2013.02.005

Bialystok, E. (2024). Bilingualism modifies cognition through adaptation, not transfer. *Trends in Cognitive Sciences, 28*(11), 987–997. https://doi.org/10.1016/j.tics.2024.07.012

Bialystok, E. (2025). Selective attention in cognitive processing revisited: A long-term Re-evaluation. *Brain and Language, 261*, Article 105518. https://doi.org/10.1016/j.bandl.2024.105518

Bicknell, K., Brust, C., & Settles, B. (2023). How Duolingo's AI Learns what you need to Learn: The language-learning app tries to emulate a great human tutor. *IEEE Spectrum, 60*(3), 28–33. https://doi.org/10.1109/Mspec.2023.10061631

Bloom, L., & Tinker, E. (2001). The intentionality model and language acquisition: Engagement, effort, and the essential tension in development. *Monographs of the Society for Research in Child Development, 66*(4). i-viii, 1–91 https://www.ncbi.nlm.nih.gov/pubmed/11799833.

Brooks, P. J., & Tomasello, M. (1999). How children constrain their argument structure constructions. *Language, 75*(4), 720–738. https://doi.org/10.2307/417731

Caldwell-Harris, C. L., & MacWhinney, B. (2023). Age effects in second language acquisition: Expanding the emergentist account. *Brain and Language, 241*, Article 105269. https://doi.org/10.1016/j.bandl.2023.105269

Cantlon, J. F., & Piantadosi, S. T. (2024). Uniquely human intelligence arose from expanded information capacity. *Nature Reviews Psychology, 3*(4), 275–293. https://doi.org/10.1038/s44159-024-00283-3

Choi, J., Broersma, M., & Cutler, A. (2017). Early phonology revealed by international adoptees' birth language retention. *Proceedings of the National Academy of Sciences of the United States of America, 114*(28), 7307–7312. https://doi.org/10.1073/pnas.1706405114

Clark, E. (2015). Common ground. In B. MacWhinney, & W. O'Grady (Eds.), *The handbook of language emergence* (pp. 328–353). New York, NY: Wiley.

de Groot, A. M. (2014). About phonological, grammatical, and semantic accents in bilinguals' language use and their cause. In *Multilingual Cognition and Language Use* (pp. 229–262). John Benjamins.

Durgunoglu, A., & Roediger, H. (1987). Test differences in accessing bilingual memory. *Journal of Memory and Language, 26*, 377–391.

Elman, J. L. (1998). In M. Gernsbacher, & S. Derry (Eds.), *Proceedings of the 20th Annual Conference of the Cognitive Science Society*. Mahwah, NJ: Lawrence Erlbaum Associates.

Flege, J. E., & Bohn, O. (2021). The revised speech learning model (SLM-r). In R. Wayland (Ed.), *Second language speech learning: Theoretical and empirical progress*. New York: Cambridge Univerrsity Press.

Flege, J. E., & Wayland, R. (2019). The role of input in native Spanish late learners' production and perception br of English phonetic segments. *Journal of Second Language Studies, 2*(1), 1–44.

Freed, B. F. (1998). An overview of issues and research in language learning in a study abroad setting. *Frontiers: The interdisciplinary journal of study abroad, 4*(1), 31–60.

Gao, Z., Wiener, S., & MacWhinney, B. (2022). Acquisition of Chinese verb separation by adult L2 learners. *Languages, 7*(3). https://doi.org/10.3390/languages7030225

Grainger, J., Midgley, K., & Holcomb, P. J. (2010). Chapter 14. Re-thinking the bilingual interactive-activation model from a developmental perspective (BIA-d). In *Language acquisition across linguistic and cognitive systems* (pp. 267–283). John Benjamins Publishing Company.

Greenacre, L., Defina, R., Akbar, S., & Garcia, J. E. (2024). Dedicated comparatives aid comparisons of magnitude: A study with Pitjantjatjara-English bilinguals. *Frontiers in Human Neuroscience, 18*, Article 1418797. https://doi.org/10.3389/fnhum.2024.1418797

Grosjean, F. (1992). Another view of bilingualism. In *Advances in psychology* (pp. 51–62). Elsevier.

Guo, D., Yang, D., Zhang, H., Song, J., Zhang, R., Xu, R., & Bi, X. (2025). DeepSeek-R1: Incentivizing reasoning capability in LLMs via reinforcement learning. *arXiv preprint arXiv:2501.12948*.

Hancin-Bhatt, B., & Nagy, W. (2015). Lexical transfer and second language morphological development. *Applied PsychoLinguistics, 15*(3), 289–310. https://doi.org/10.1017/s0142716400065905

Harris, R. J. (1992). *Cognitive processing in bilinguals*. Elsevier.

Hartsuiker, R. J., Pickering, M. J., & Veltkamp, E. (2004). Is syntax separate or shared between languages? Cross-linguistic syntactic priming in Spanish-English bilinguals. *Psychological Science, 15*(6), 409–414. https://doi.org/10.1111/j.0956-7976.2004.00693.x

Hernandez, A., Li, P., & MacWhinney, B. (2005). The emergence of competing modules in bilingualism. *Trends in Cognitive Sciences, 9*(5), 220–225. https://doi.org/10.1016/j.tics.2005.03.003

Hintzman, D. L. (2011). Research strategy in the study of memory: Fads, fallacies, and the search for the "coordinates of truth". *Perspectives on Psychological Science, 6*(3), 253–271.

Jespersen, O. (1922). *Language: Its nature, development, and origin*. London: George Allen & Unwin.

Kang, S. H., Lindsey, R. V., Mozer, M. C., & Pashler, H. (2014). Retrieval practice over the long term: Should spacing be expanding or equal-interval? *Psychonomic Bulletin & Review, 21*(6), 1544–1550. https://doi.org/10.3758/s13423-014-0636-z

Karmiloff-Smith, A. (1979). *A functional approach to child language: A study of determiners and reference*. New York, NY: Cambridge University Press.

Karniol, R. (2010). *Social development as preference management: How infants, children, and parents get what they want from one another*. Cambridge University Press.

Kemmerer, D. (2015). *The cognitive neuroscience of language*. New York, NY: Psychology Press.

Kirsner, K. (1986). Lexical function: Is a bilingual account necessary? In J. Vaid (Ed.), *Language processing in bilinguals: Psycholinguistic and neuropsychological perspectives*. London: Lawrence Erlbaum Associates.

Köpcke, K.-M. (1996). Prinzipien für die Genuszuweisung im Deutschen. In E. Lang, & G. Zifonun (Eds.), *Deutsch - typologisch*. Berlin: Walter de Gruyter.

Kowalski, J., Zhang, Y., & MacWhinney, B. (2014). Statistical modeling of student performance to improve Chinese dictation skills with an intelligent tutor. *Journal of Educational Data Mining, 6*, 3–27.

Kroll, J., & Dussias, P. (2024). Beyond transfer: language processing in bilinguals is shaped by competition and regulation. *Language Teaching Research Quarterly, 44*, 55–70.

Kuperberg, G. R., & Jaeger, T. F. (2016). What do we mean by prediction in language comprehension? *Language, Cognition and Neuroscience, 31*(1), 32–59. https://doi.org/10.1080/23273798.2015.1102299

LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *Nature, 521*(7553), 436–444. https://doi.org/10.1038/nature14539

Lee, D., Seo, H., & Jung, M. W. (2012). Neural basis of reinforcement learning and decision making. *Annual Review of Neuroscience, 35*(1), 287–308. https://doi.org/10.1146/annurev-neuro-062111-150512

Lemhofer, K., & Broersma, M. (2012). Introducing LexTALE: A quick and valid lexical test for advanced learners of English. *Behavior Research Methods, 44*(2), 325–343. https://doi.org/10.3758/s13428-011-0146-0

Lenneberg, E. (1967). *Biological foundations of language*. New York, NY: Wiley.

Li, P., Farkas, I., & MacWhinney, B. (2004). Early lexical development in a self-organizing neural network. *Neural Network, 17*(8–9), 1345–1362. https://doi.org/10.1016/j.neunet.2004.07.004

Li, P., Zhang, F., Tsai, E., & Puls, B. (2014). Language history questionnaire (LHQ 2.0): A new dynamic web-based research tool. *Bilingualism: Language and Cognition, 17*(3), 673–680.

Liu, A., Feng, B., Wang, B., Wang, B., Liu, B., Zhao, C., & Guo, D. (2024). Deepseek-v2: A strong, economical, and efficient mixture-of-experts language model. *arXiv preprint arXiv:2405.04434*.

MacWhinney, B. (1989). Competition and connectionism. In B. MacWhinney, & E. Bates (Eds.), *The crosslinguistic study of sentence processing* (pp. 422–458). New York, NY: Cambridge University Press.

MacWhinney, B. (1992). Transfer and competition in second language learning. In R. Harris (Ed.), *Cognitive processing in bilinguals* (pp. 371–390). Amsterdam: Elsevier.

MacWhinney, B. (2008). How mental models encode embodied linguistic perspectives. In R. Klatzky, B. MacWhinney, & M. Behrmann (Eds.), *Embodiment, Ego-Space, and Action* (pp. 369–410). Mahwah, NJ: Lawrence Erlbaum.

MacWhinney, B. (2012). The logic of the Unified Model. In S. Gass, & A. Mackey (Eds.), *The Routledge Handbook of Second Language Acquisition* (pp. 211–227). New York, NY: Routledge.

MacWhinney, B. (2015). Emergentism. In E. Dabrowsksa, & D. Divjak (Eds.), *Handbook of Cognitive Linguistics* (pp. 689–706). New York, NY: Mouton-DeGruyter.

MacWhinney, B. (2017). A shared platform for studying second language acquisition. Retrieved from *Language Learning, 67*, 254–275 https://psyling.talkbank.org/years/2017/SharedPlatform.pdf.

MacWhinney, B. (2018). A unified model of first and second language learning. In M. Hickmann, E. Veneziano, & H. Jisa (Eds.), *Sources of variation in first language acquisition* (pp. 287-312).

MacWhinney, B. (2019). Language attrition and the Competition Model. In M. Schmid, & B. Köpke (Eds.), *The Oxford Handbook of Language Attrition*. New York: Oxford University Press.

MacWhinney, B. (2021). The Competition Model: Past and Future. In J. Gervain (Ed.), *A life in cognition* (pp. 3–16). New York: Springer Nature.

Manning, C. D., Clark, K., Hewitt, J., Khandelwal, U., & Levy, O. (2020). Emergent linguistic structure in artificial neural networks trained by self-supervision. *Proceedings of the National Academy of Sciences of the United States of America, 117*(48), 30046–30054. https://doi.org/10.1073/pnas.1907367117

McManus, K., Mitchell, R., & Tracy-Ventura, N. (2021). A longitudinal study of advanced learners' linguistic development before, during, and after study abroad. *Applied Linguistics, 42*(1), 136–163.

Montrul, S., & Yoon, J. (2019). Morphology and language attrition. *Oxford Research Encyclopedia of Linguistics*. Oxford University Press, Oxford.

Morgan-Short, K., & van Hell, J. G. (2023). *The Routledge Handbook of Second Language Acquisition and Neurolinguistics*. Taylor & Francis.

Nandi, A., Manning, C. D., & Murty, S. (2024). Sneaking syntax into transformer language models with tree regularization. *arXiv preprint arXiv:2411.18885*.

Nassar, M. R., Helmers, J. C., & Frank, M. J. (2018). Chunking as a rational strategy for lossy data compression in visual working memory. *Psychological Review, 125*(4), 486–511. https://doi.org/10.1037/rev0000101

Patterson, K., & Ralph, M. A. L. (2016). The hub-and-spoke hypothesis of semantic memory. In *Neurobiology of Language* (pp. 765–775). Elsevier.

Pecher, D., & Zwaan, R. (Eds.). (2005). *Grounding Cognition*. Cambridge: Cambridge University Press.

Pienemann, M., Di Biase, B., Kawaguchi, S., & Håkansson, G. (2005). Processing constraints on L1 transfer. In J. Kroll, & A. M. B. DeGroot (Eds.), *Handbook of bilingualism: Psycholinguistic approaches* (pp. 128–153). New York, NY: Oxford University Press.

Ratcliff, R., Van Zandt, T., & McKoon, G. (1999). Connectionist and diffusion models of reaction time. *Psychological Review, 106*(2), 261–300. https://doi.org/10.1037/0033-295x.106.2.261

Schrimpf, M., Blank, I. A., Tuckute, G., Kauf, C., Hosseini, E. A., Kanwisher, N., & Fedorenko, E. (2021). The neural architecture of language: Integrative modeling converges on predictive processing. *Proceedings of the National Academy of Sciences of the United States of America, 118*(45), Article e2105646118. https://doi.org/10.1073/pnas.2105646118

Shain, C., Blank, I. A., van Schijndel, M., Schuler, W., & Fedorenko, E. (2020). fMRI reveals language-specific predictive coding during naturalistic sentence comprehension. *Neuropsychologia, 138*, Article 107307. https://doi.org/10.1016/j.neuropsychologia.2019.107307

Slobin, D. I. (1988). *Thinking for speaking*. Berkeley, CA: Society.

Snow, C. E., & Hoefnagel-Hohle, M. (1978). The critical period for language acquisition: Evidence from second language learning. *Child Development, 49*, 1114–1128.

Titone, D. A., & Tiv, M. (2022). Rethinking multilingual experience through a Systems Framework of Bilingualism. *Bilingualism: Language and Cognition, 26*(1), 1–16. https://doi.org/10.1017/s1366728921001127

Titone, D. A., & Tiv, M. (2023). Rethinking multilingual experience through a systems framework of bilingualism: Response to commentaries. *Bilingualism: Language and Cognition, 26*(1), 247–251. https://doi.org/10.1017/s1366728922000785

Valiant, L. G. (2012). The hippocampus as a stable memory allocator for cortex. *Neural Computation, 24*(11), 2873–2899. https://doi.org/10.1162/NECO_a_00357

Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A. N., . . . Polosukhin, I. (2017). Attention Is All You Need. *Advances in Neural Information Processing Systems 30 (Nips 2017), 30*. Retrieved from <Go to ISI>://WOS:000452649406008.

Verbeek, L., Vissers, C., Blumenthal, M., & Verhoeven, L. (2022). Cross-language transfer and attentional control in early bilingual speech. *Journal of Speech, Language, and Hearing Research: JSLHR, 65*(2), 450–468. https://doi.org/10.1044/2021_JSLHR-21-00104

Werker, J., & Hensch, T. (2014). Critical periods in speech perception: New directions. *Annual Review of Psychology, 66*, 173–196. https://doi.org/10.1146/annurev-psych-010814-015104

Yip, V., & Matthews, S. (2000). Syntactic transfer in a Cantonese-English bilingual child. *Bilingualism: Language and Cognition, 3*, 193–208.

Zevin, J. D. (2012). A sensitive period for shibboleths: The long tail and changing goals of speech perception over the course of development. *Developmental Psychobiology, 54*(6), 632–642. https://doi.org/10.1002/dev.20611

Zhao, H., Vanek, N., & MacWhinney, B. (2025). Mental simulation in bilingual and second language processing: New directions in the competition model. *Brain and Language, 243*.