

From the Spatial Ego to Cognitive Control:
Ellen Bialystok's Early Work, 1976 - 1988

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Sibylla's note

Ellen Bialystok is perhaps best known for her brilliant insights into bilingualism and its modulation of multiple cognitive processes across the lifespan: metalinguistic awareness, executive functions, and protection from the deleterious symptoms of Alzheimer's disease and other forms of dementia in aging. Her most highly cited publications enumerated in Web of Science (Web of Science, n.d.) encompass all of these topics highlighting the consequences of bilingualism for the mind and brain, the eponymous title of her second most highly cited scientific publication (Bialystok et al., 2012). In most of Ellen Bialystok's media interviews as well, such as that in the New York Times (Dreifus, 2011), you are likely to hear something that includes 'the bilingual advantage', 'executive functions' or 'cognitive control'. My own introduction to Ellen Bialystok as the individual and intellect behind these foundational discoveries in the cognitive science of bilingualism was admittedly vicarious. It was the first-hand experiences and anecdotes of Bialystok's former student and my PhD advisor, Gigi Luk, that brought this intellectual legend to life, much as ancestors are reincarnated through stories passed down across generations.¹ In this case, the ancestor is a contemporary pioneer and founder of the cognitive study of bilingualism, driving current innovation in theory and methodology of bilingual language processing while the legends are the cognitive consequences of bilingualism.

"Not the bilingualism stuff"

While her work on bilingual cognition may be the most well-known and controversial contribution of the later Bialystokean oeuvre, Bialystok's earliest investigations into language experience and education are equally, if not more, important in constructing a foundation for the contemporary study of bilingualism. When interviewed in 2018, Bialystok surprises: "my most important contribution was NOT the bilingualism stuff, but... the very first thing I did after my Ph.D." (Gordon, 2018). She goes on to identify her most significant scholarly work as something more fundamental than comparisons of bilingual and monolingual executive function, namely,

¹ Although festschrift chapters are conventionally written by the contemporaries or first generation of the honoree, as a heritage (and arguably attriting) Bialystokean, I have leaned heavily on David Schleicher's helpful and hilarious festschrift and guide: Schleicher (2013). From here all-the-way-down, or how to write a festschrift piece. *Tulsa Law Review*, 48(3), pp. 401-425.

her innovation in uniting language and cognitive processes in a novel model of second language acquisition. Bialystok first introduced the idea of the separate but interacting roles of language and cognition in her Ph.D. dissertation on learning of spatial concepts. She then largely turned away from studying spatial and mathematical cognition after completing the thesis (though see [Bialystok & Codd, 1987, 1996, 1997](#); [Codd & Bialystok, 1985](#) for further work in this field) and went on to articulate a full theoretical model of second language learning in 1978, continuing this line of work over the next decades. A quick peek at Bialystok's Google Scholar web page (accessed June 11, 2021), which includes scholarly literature more broadly, provides a hint at the impact of this 1978 paper, one of the first published in her prolific and illustrious career, cited an astounding 1,482 times. What is contained in this 1978 work, *A Theoretical Model of Second Language Learning* (Bialystok, 1978), and how could Bialystok esteem this more than any of her work on metalinguistics, executive functions, or aging?

Starting with *A Theoretical Model* (1978) Bialystok introduced into the study of bilingualism a novel way of thinking about language acquisition and processing that incorporated cognitive processes. This line of research and theory building prompted an entire branch of applied linguistics looking at cognitive functions as fundamental building blocks of language. Bialystok, in essence, brought the cognitive revolution to the study of bilingualism in just a few short years at the end of the 1970's. By the 1990's, this field had exploded and continues to grow to the present day, with citations to Bialystok's work seen in Figure 1, reaching beyond linguistics and psychology to education, speech and hearing sciences, and neuroscience. It is quite rare for academic research to have such far-reaching impact both within and across multiple disciplines and a testament to the intellectual innovation and power in her career.

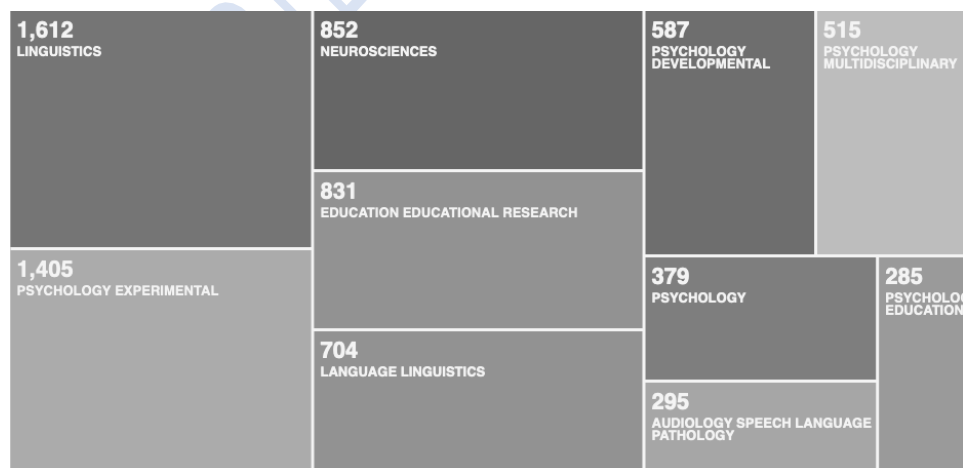


Figure 1. Subject areas and Web of Science citation counts for Bialystok's scientific publications, 1970-2021

The present chapter highlights Bialystok's early, and sometimes overlooked, contributions to the field from the publication of her dissertation in 1976 to the cognitive models of the 1980's and early 1990's that made this explosion of research possible. The chapter briefly reviews two crucial strands in Bialystok's early work: the first strand develops an information processing model of language at the word level that highlights the role of cognitive processes in language representation, particularly in the context of second language acquisition. The second strand characterizes the quantitative continuum and complexity of language experience, presaging a contemporary call to attend to nuance in characterizing bilinguals. After reviewing these two themes in Bialystok's early work, the chapter next discusses the underlying tension between the information processing model and an accounting of complex language experience, namely the difficulty of resolving complex, top-down contingencies with a theoretical model that separates language and cognition, particularly when language is modeled at the word level. That Bialystok is popularly associated with a 'bilingual advantage' suggests that the information processing model of bilingualism has privileged and reified isolated cognitive systems (e.g., intelligence, executive functions, and/or attention) as the backbone of language processing. As a result, there has been a research shift towards the comparative cognitive advantages of bilingualism to the detriment of characterizing the complexity of language experience. Finally, we conclude by illustrating new directions in bilingualism research that have been made possible by Bialystok's early work, using our own and other new scholars' research as examples. Building on the groundwork laid by Bialystok from the 1970's with second language learning, the 1980's in applied linguistics, the 1990's moving into cognitive psychology, we thus trace Bialystok's steps backwards and bringing a pendulum of research full circle, from education to language to cognition and neuroscience, and then back to language and education again.

Bringing cognition to language: Information processing models of bilingualism

While Bialystok's lifelong contributions have centered around bilingualism, she brought to this work a theoretical and nuanced understanding of language development from her dissertation research on a completely different topic: young children's development of mathematical concepts of spatial relations. Her 1976 thesis, *The Development of Spatial*

Concepts in Language and Thought (Bialystok, 1976), exemplifies Bialystok's research approach to the study of language and foreshadows two contributions that guided the development of the cognitive study of bilingualism in later years: 1) the formulation and empirical testing of new theoretical models to replace structuralist and constructivist stage theories, and 2) a critique of purely modular linguistic analysis accompanied by a focus on separating cognitive processing from word-level language representation.

In Bialystok's thesis, these contributions center around the language of mathematical concepts of spatial relationships: she critiques Piaget's ideas that children's development of spatial concepts arises from psychological stages (the detachment from egocentrism and topological space) or from acquisition of formal conceptual categories (Euclidian space) with empirical evidence that spatial egocentrism was not a consistent qualitative feature of children's descriptions of spatial relationships. Bialystok also warns against confounding specific language representations of spatial relationships with an underlying conceptual representation of space, highlighting the need for a cognitive theory of spatial development that, while not identical with language development, could still explain children's developing language around spatial relationships. The dissertation details this cognitive theory by connecting children's growing conceptual understanding of object permanence or invariance with the use of words that describe spatial relationships. Bialystok's model of mathematical development did not fully adopt an information processing perspective as it sought to describe the distinct development of linguistic and conceptual representations rather than model cognitive processes operating upon linguistic representations of spatial concepts as a true information processing model would. However, the inclusion of both language and cognitive processes, along with their clear distinction from one another in this model would presage her later work on second language acquisition.

The same intellectual move of developing new theoretical models based on information processing theory that distinguish linguistic and conceptual processes informs Bialystok's subsequent contributions to the study of bilingualism. In *A Theoretical Model of Second Language Learning* (Bialystok, 1978), Bialystok expanded her initial models of second language learning from an information processing perspective, specifying distinct yet interconnected roles for language representations and cognitive processes. Inputs to the model come from a continuum of linguistic experiences while linguistic behaviors are outputs. Information within the model system is stored as three forms of knowledge: explicit knowledge of language rules;

unconscious, implicit linguistic representations; and pragmatic, or other knowledge about the world and about language context that informs language use (Bialystok, 1978, 1979a, 1979b). Although called learning strategies and grouped with other learning strategies such as formal and functional practice in this early model, Bialystok identified two core cognitive processes as critical for shaping the paths from input to knowledge to output: monitoring, drawing from Krashen (1977, as cited in Bialystok, 1978) and inferencing, drawing from Carton (1976, as cited in Bialystok, 1978). Bialystok postulated monitoring as a control strategy for production in which learners examined and corrected their output, while inferencing was a metalinguistic strategy for comprehension through which learners generalized known linguistic information about word forms or meanings to unknown words (Bialystok & Howard, 1979). These two learning strategies are the early precursors of Bialystok's later focus on cognitive control and metalinguistic skill as core cognitive processes that govern bilingual language use and acquisition (Bialystok, 1986a, 1987b; Bialystok & Ryan, 1985) as well as the development of linguistic concepts (Bialystok, 1986b) and optimal teaching and learning strategies (Bialystok, 1985).

In the burgeoning field of cognitive psychology of the 1970's and 80's, increasing attention was being drawn to characterizing cognitive control processes as part of information processing models, such as those articulated by David Green's bilingual control, activation and resource (1986), Norman and Shallice's attention and control (1986) and Baddeley's working memory (Baddeley & Hitch, 1974) models. As early as 1981 in *The Role of Linguistic Knowledge in Second Language Use* (Bialystok, 1981), Bialystok began to distinguish between linguistic knowledge and access to that knowledge in the bilingual domain, drawing from cognitive psychology and epistemology to model control over language as part of a second language processing model. By 1985, Bialystok's articulation of monitoring and inferencing as learning strategies in the 1978 second language learning model had evolved into a predominant focus on cognitive control and metalinguistic knowledge, defined as knowledge that has been analyzed and structured in an appropriate framework. *Towards a Definition of Metalinguistic Skill* (Bialystok & Ryan, 1985) placed these two skills of accessing and structuring linguistic knowledge respectively in a two-dimensional matrix as cognitive skills shaping the development of language competence. Along the control dimension, children's increasing mastery of executive processes such as attention and memory allows for increasing access to analysis of

knowledge, while along the structure dimension, increasing levels of analyzed knowledge characterize increasingly expert language use. Bialystok's articulation of second language acquisition and processing models continued to evolve after this early work, reflecting new research and shifts in both theories and methods in cognitive psychology. However, her dissertation in mathematics learning and early second language acquisition model formed the foundation of a trailblazing insight into the relevance of cognitive processes and information processing theory for the modeling of language development and an enduring legacy that has shaped the field of bilingualism research.

The complexity of language experience

While the cognitive model of bilingualism is Bialystok's most cited influence on bilingualism research, the second strand of her early research is no less consequential: articulating language development as a complex phenomenon described, 1) not in categorical stages but along a continuum of experience and 2) with multiple contextual factors. This strand first emerged in Bialystok's dissertation search for a cognitive model to replace constructivist and stage theories of mathematical development. Bialystok's new mathematical theory was rooted in constructivism, maintaining a teleological perspective on mathematical development with ultimate attainment of a "co-ordinated dimensional system" (Bialystok, 1976, p. 184) with corresponding spatial concepts and language as the end goal. Unlike in Piagetian and other constructivist and structuralist stage theories of the time, in Bialystok's model this development occurs along a quantitative continuum, with increasing spatial experience providing richer spatial representations and more complex spatial language. To replace Piaget's qualitative stages of egocentric, topological reasoning vs. Euclidian reasoning, Bialystok proposed that children acquire spatial concepts following a continuum of spatial complexity, with spatial relationships that are simpler in terms of having fewer dimensions (e.g. one-dimensional horizontal relationships vs. two-dimensional diagonal relationships) and that are more robust (invariant) to changes in the child's position (e.g. something on top of vs. behind a table) learned earlier. Children's spatial development in Bialystok's new model occurs as with increasing experience using language to represent spatial observations, they are able to juggle increasingly complex information about spatial locations and apply their knowledge to novel and varied experiences, forecasting the ideas of monitoring and inferencing strategies as core cognitive processes in her

later linguistic model. Indeed, Bialystok carried over, not only the ideas of coordination/control and inference, but also her insight into the role of a quantitative continuum of multifactorial experience, knowledge and skill in both language and cognitive development into her understanding of second language acquisition.

Just as her dissertation drew on empirical work with children to refute modular stage theories of mathematical reasoning, Bialystok's modeling of second language learning also drew heavily on empirical research, this time with the classroom acquisition of French, to develop a theory of language that was far from the then dominant Chomskyan formulation of innate language modules (Chomsky, 1965). While Bialystok recognized the role of different methodological tools in addressing different research questions, her early work evaluating mathematical and language outcomes was accompanied by a focus on quantitative experimental tools (Bialystok & Swain, 1978). Bialystok's earliest post-dissertation work comprised a series of reports evaluating classroom conditions for the teaching and learning of French as a second language. This research was funded by the Ministry of Education in Ontario, Canada, in the decade following the 1968 publication of the Royal Commission's recommendation that all children be required to learn both official languages (i.e., classes in French as a second language for Ontario's majority Anglophone population) and the 1969 adoption of French as a second official language at the national level through the Official Languages Act (Dagenais, 1988). The resultant expansion of publicly funded French education in Ontario and across the country adopted traditional foreign language instruction and, in some cases, immersion programs originated in Québec. Accordingly, Bialystok was engaged in a provincial research program that sought to better understand the characteristics and conditions of second language teaching and learning. A series of analyses based on data collected through this research comprise Bialystok's first post-dissertation publications in bilingual education.

Leading the series was a mixed-methods study comparing classroom experiences and language exposure in conventional foreign language ("Core") compared to immersion classrooms. Bialystok outlined preliminary results of this project in her first post-dissertation publication, *Second language learning and teaching in classroom settings: The learning study, year one* (Bialystok & Fröhlich, 1977), followed by an expanded report in 1978 detailing first her research findings on teaching practices and second on learning outcomes. This latter two-part report, *The Teaching and learning of French as a second language in two distinct learning*

settings (Bialystok et al., 1978), identifies the complexity of factors that influence second language learning. Throughout the report, Bialystok's primary focus remains on linguistic analysis, with an underlying assumption that regardless of classroom structure, it is linguistic experience that exerts the primary influence on language learning.

On the teaching side, Bialystok developed and utilized a classroom observation instrument based on prior work (Bellack, 1966, as cited in Bialystok et al., 1978) that identified distinct linguistic 'moves' or functional behaviors, and the discourse functions that supported these behaviors, as measurable analytic items in the linguistic analysis of classroom interactions. For example, linguistic moves such as initiating dialogue, soliciting information, responding to solicitations, and reacting to prior discourse might be supported by discourse functions such as giving directions, disciplining, modeling, clarifying, translating, or even noise and laughter. While immersion learning is often considered more effective than traditional classroom instruction due to immersion students' greater use of the target language, by analyzing moves and discourse functions as elements of linguistic experience in the classroom, Bialystok revealed that immersion as compared to core classrooms also provided a greater variety of linguistic moves and discourse functions and a more flexible and complex linguistic experience.

On the learning side, Bialystok added similar nuance in her year 1 report (Bialystok & Fröhlich, 1977) using multiple analytic elements of learner characteristics in language acquisition. In these early studies, Bialystok parsed individual characteristics into factors of attitude and motivation, language aptitude, cognitive 'style', visuospatial perception, and use of learning strategies (Bialystok & Fröhlich, 1978). Language outcomes, or competence, was similarly broken down into modalities, either oral and written, with each modality further divided into explicit (formal) knowledge of linguistic rules and implicit (functional) ability. As with the teaching study, Bialystok's early examination of language learning revealed variable and complex relationships between the component predictors and outcomes of second language learning. At present, Bialystok's work is most strongly associated with a focus on cognitive variables such as working memory, executive functions and attention. However, Bialystok herself advocated even in this earliest project for a nuanced and multifactorial understanding of both predictors and outcomes in bilingualism. Bialystok & Fröhlich (1978) describe an exclusive focus on cognitive rather than affective variables may be misleading:

“One set of factors has not distinguished itself as the most essential to the exclusion of the other. Rather, different situations may specify various combinations of these factors for maximum success. It may also be the case that language learners deficient in one set of these factors can compensate by accentuating the other.” (p. 335)

Although Bialystok’s work following the initial classroom learning project focused more on learner variables than pedagogical ones, this early work exemplified the nuanced analytic and componential approach to understanding bilingualism as a complex language experience that characterizes her work and influence on the field of bilingualism research to this day.

Information processing models and bilingual complexity: person and process

Bialystok’s research and theoretical work, grounded in her early study of classroom learning, introduced the idea of the primacy of cognitive processing to the study of second language acquisition at a time when word representations were thought to define development. Her work in highlighting the continuum and complexity of bilingual experience and in articulating an information processing model for second language acquisition have both been critical in shaping the field of bilingualism research.

At the process level, research emerging from Bialystok’s work on cognitive models has motivated the study of cognitive aspects of bilingualism. Rather than describing language development in qualitative stages, Bialystok’s early theoretical model described the learning process as a continuous advancement of linguistic knowledge and processing skill towards native-like proficiency. The information processing model both introduced cognitive processes to language representations but also separated them, privileging the former while primarily characterizing the latter at the single word level. In this model, word level stimuli act as bottom-up input governed by a top-down control process. This focus on cognition and specifically on cognitive control exploded in the study of bilingualism, resulting in the influential citations and media interpretations of Bialystok’s cognitive work referenced in the introduction to this chapter. Described in greater detail in subsequent chapters in this volume (e.g., Kroll & Rossi; Craik), this work greatly expands the concept of monitoring that Bialystok identified as a learning strategy in her first theoretical model into an expansive research field examining cognitive control constructs such as attention, inhibition and executive function as they relate to potential differences between bilingual and monolingual cognition.

The power of the information processing model to motivate research on bilingualism lay not only in its capacity to explain experimental data and account for both cognition and language, but also in its role as a building block of a backlash in bilingualism research against societal prejudices towards bilingualism. From early on, Bialystok was keenly aware of this prejudice exemplified in colonial era work (Bialystok, 1987b) such as that by D.J. Saer (1923) finding that poorer Welsh-English bilinguals were less intelligent than more advantaged English monolinguals. 20th century pioneers in bilingual education research such as Peal & Lambert (1962) revealed a different scenario in multilingual Montréal, Canada, where bilingual children showed advanced mental abilities when accounting for demographic variables such as socioeconomic status and in a community where English and French permeated in all social interactions. While the debate over mental superiority has shifted from intelligence to cognitive control and executive functions as indicators of cognitive capacity and efficiency (P. H. Miller & Scholnick, 2015), questions of societal prejudice and demographic confounders remain. Already in 1987, Bialystok argued that research on bilingual intellectual differences needed to account for different levels and types of bilingual experience, different linguistic tasks, and different sociodemographic factors (Bialystok, 1987a). Since then, much of the work in the cognitive study of bilingualism has taken an empirical, positivist approach to the question of intellectual superiority by refining cognitive models (e.g., Deluca et al., 2020; Grundy et al., 2017, 2020; Pliatsikas et al., 2020), separating independent and confounding variables (e.g., Thomas-Sunesson et al., 2018), and demonstrating causal effects or lack thereof (e.g., Li & Grant, 2015; Woumans et al., 2019; Yamasaki et al., 2019). Nevertheless, whether bilinguals differ in core cognitive abilities from monolinguals as a result of their language experience remains a historically and socially charged question both rooted in and responding to a colonial era question with no definitive modern answer.

In contrast at the person level, subsequent research building on Bialystok's move from understanding language as discrete representations managed by control processes into rather a continuum of experience has characterized the many factors that shape diverse bilingual experience and moved the study of bilingual experience in a much different direction. Much of Bialystok's work has categorically compared monolinguals and bilinguals, who might appear to be easily defined as those who speak one versus more than one language. However, these labels encompass a wide range of linguistic and social experiences (Luk, 2015; Luk & Bialystok,

2013). At one extreme is the idealized monolingual native speaker with high proficiency, frequent and rich L1 exposure from birth (or prenatally), and little or no exposure to other languages. This potentially mythical individual has long been considered a standard by which to evaluate monolingual language processing (May, 2019). At the opposite extreme and equally mythical, is the perfectly balanced bilingual, two perfect monolinguals in one (an ideology sternly warned against by Grosjean, 1989). However, on both extremes, these idealized standards are not realistic representations of either monolingual or bilingual communities. For monolinguals, the standard of the ideal native speaker overlooks language variation that may be tied to geographic areas, class, culture, ethnicity, political, and interactional contexts. In the U.S., for example, historical conditions of slavery and raciolinguistic identification (Rosa & Flores, 2017) means that the language of (often monolingual) native English speakers who speak African American English (AAE) is stigmatized (Labov, 1982; Rickford, 1999), and its use in school contexts has been associated with poor literacy outcomes (Brown et al., 2015; Terry et al., 2016). For bilinguals, the native monolingual standard overlooks the coexistence and interaction of two (or more) languages in one individual that render both the native and the second languages different from the language of a monolingual speaker (Kroll et al., 2012). Similarly, Bialystok's early formulation of language experience as a quantitative continuum and not a categorical divide has been expanded to the neuroscience field by research finding that the neural representation of a bilingual's languages depends not only on the age at which the languages are acquired, but also the context of acquisition, relative and absolute levels of proficiency, linguistic partners and contexts, and daily language use for each of the speaker's languages (Cargnelutti et al., 2019; DeLuca et al., 2019; Pliatsikas et al., 2020; Rossi et al., 2017).

Bialystok's work on bilingual complexity has thus seeded a literature that sits at the border of a post-positivist (cf. Lincoln et al., 2011) approach in which the diversity and complexity of language experience entails that no single model can accurately describe bilingual language acquisition and processing. Rather, a multiplicity of variables, sometimes organized into latent constructs, are required to provide windows of insight into a heterogeneous landscape of bilingual experience (Navarro-Torres et al., 2021).

As the process and person strands of research grounded in Bialystok's earliest work have expanded and taken on a life of their own, fundamental tensions have emerged between the themes of cognition and complexity at the core of Bialystok's oeuvre. While word level

information processing models allow for a clear, analytic theory and testing of well-defined elements of language and cognition in the laboratory context, one difficulty they present is that they do not account for heterogeneity and complexity in language processing, both at the person level, influenced by experience, motivation, affect, and social context, for example; and at the process level, particularly in higher order sentence and discourse level processing. Constructed to explain word level processing, Bialystok's model was intended to be general enough to apply to all humans and all second language acquisition, regardless of individual variability in skill, motivation, context, level, etc. Bialystok explains, "It does not describe differences between language learners.... Differences in achievement between individual as are attributed to differences in the efficiency with which the model operates for different people" (Bialystok, 1978, p. 70). The tension between the universality of a general cognitive model and the heterogeneity of both individual and social variation in human language, in an instructively constructivist manner, also provides opportunities for new directions in research, which we discuss below.

*Cognitive models and complexity at the **person** level*

One way of addressing complexity at the person level and moving beyond the teleological model of ultimate attainment to a monolingual standard in bilingualism research is to engage with within-group studies of linguistically diverse populations. At the person level, increasing recognition of diverse linguistic populations provides evidence that bilingualism is a multidimensional experience (Grosjean, 2013; Luk, 2015): age of acquisition (Rossi et al., 2014), proficiency (Newman et al., 2011), learning context and motivation (Tanner et al., 2013), and the interactional contexts in which a bilingual's two languages are used (Beatty-Martínez et al., 2020; Kaan et al., 2020) all introduce variation into the way in which bilinguals use both their languages. Two examples of this variation are groups not typically considered 'true' bilinguals in the past but increasingly recognized as such, namely speakers of dialectal varieties and heritage language speakers who typically lose proficiency in their home language when immersed in the dominant societal language (Polinsky & Kagan, 2007).

Both groups have historically been described as having language deficits in comparison with monolingual native speakers of both the home and the socially dominant language (Bayram et al., 2020), but research increasingly addresses both heritage and bidialectal language systems

as systematic and efficient adaptations to specific language environments (Bayram et al., 2020). For example, heritage bilinguals may adopt unique strategies for phonological processing (Martohardjono et al., 2017), lexical access (Wiener & Tokowicz, 2019), and syntactic processing (Stern et al., 2019), depending on their age of second language acquisition and proficiency. Varying conditions and ages of exposure to the dominant societal language and varying contexts of continued home language use entail that heritage speakers possess heterogeneous proficiencies and patterns of bilingual language use (Abutalebi & Clahsen, 2020; Polinsky & Scontras, 2019). Even when heritage speakers are fully proficient in the societal language, their early experience of linguistic diversity can be seen in underlying processing.

In one of few published electrophysiological (EEG) studies of sentence processing in heritage speakers, Bice and Kroll (2021) examined two commonly studied EEG signatures of sentence processing called the N400 and P600 responses. This EEG activity was measured as participants read sentences containing verbs that violated standard English subject-verb agreement rules of number (singular verb with ‘-s’ vs. plural without ‘-s’). Monolingual English speakers came from an English-dominant college community in Pennsylvania and heritage Spanish-English bilinguals, whose first and childhood home language was Spanish, came from a linguistically diverse community in California. Both groups were English-dominant and matched in English proficiency yet displayed different neural signatures of grammatical processing as well as different behavioral correlates of those signatures. In sum, heritage speakers displayed early behavioral and neural adaptations as a consequence of processing the home language and the language of the community from early life (Chang, 2019). A single model of language processing based on a teleological continuum that culminates in ‘native-like’ proficiency is thus insufficient to describe the full range of language experience.

Another example of diversity within systematic language variation in phonology, lexicon and grammar can be found in dialects, or varieties of languages. Dialects are often mutually intelligible, sharing some global semantic, structural and phonological properties, while presenting more subtle differences in phonology and grammar (Chambers & Trudgill, 1998). For monodialectal speakers, EEG studies of speech sound perception with mismatch negativity paradigms (MMN, an indicator of perception of a phonetic anomaly) show that dialectal allophones are perceived differently by individuals depending on an individual’s prior exposure to those dialects. This finding has been demonstrated for speakers of regional varieties of many

languages, including German (Bühler et al., 2017; Lanwermyer et al., 2016), Italian (Miglietta et al., 2013), French (Brunellière et al., 2011), English (Conrey et al., 2005), and Chinese (Tang et al., 2020). Further, proficient bi-dialectal speakers process speech sounds of the shared dialect differently than speakers with only a single dialect, as evidenced in behavioral (Berthele, 2008), EEG (Bühler et al., 2017), eye-tracking (Lundquist & Vangsnes, 2018) and fMRI (Schmitt et al., 2018) paradigms.

For the lexicon and grammar, there is similar evidence that proficient language processing may occur in different ways depending on an individual's experience with language variation, including among bidialectal Mandarin Chinese speakers, Li et al. (2020), spoken and standard Arabic speakers (Khamis-Dakwar & Froud, 2014) and African American English speakers (Garcia, 2017; Weissler & Brennan, 2020). Factors in this work found to influence electrophysiological signatures of language processing in bidialectal listeners include the linguistic characteristics of the dialect pair, age of dialect acquisition, extent of dialect switching as well as context of use, as well as participants' perception of speaker identity (Weissler & Brennan, 2020). Listeners' expectations and prior experience of dialectal speech thus shape language processing for bidialectal individuals.

Our own work with highly proficient multidialectal English readers (in preparation) has extended this finding to written language. We examined English sentence processing in highly proficient readers from English-speaking Caribbean nations who spoke multiple English dialects. Given these Caribbean English bidialectals' high levels of proficiency and early age of standard English acquisition, they might be expected to process written English much as monodialectal, monolingual speakers do, displaying greater N400 and P600 responses when reading ungrammatical as opposed to grammatical sentences. However, bidialectals did not display these N400 or P600 amplitude modulations with ungrammatical sentences. Another expectation was that given this group's acquisition of English as their first and only language and high levels of proficiency, individual differences in those variables would not be significantly associated with ERP responses. Again, this expectation was contradicted by the finding that bidialectals with earlier general English exposure displayed greater N400 responses to ungrammatical sentences. From the perspective of the N400 as an index of prediction (Kuperberg et al., 2020), these results suggest that dialectal experience thus seems to dampen surprisal or preference and is associated with linguistic flexibility in accommodating early lexical access. When presented with variability

in verb forms and a demand for interpretation, as in this study's sentence integration paradigm, bidialectals may be shifting attention away from the grammar towards lexical processing. Similar results in the auditory modality were found by Weissler and Brennan (2020), with no N400 or P600 effects in bidialectal speakers for the ungrammatical verb form when sentences were verbally presented in AAE.

Our finding that bidialectals whose exposure to standard English was delayed had smaller N400 responses to dialectal verb forms than bidialectals with earlier standard English exposure also suggests that longer exposure to home language forms amplifies their predictability and/or preference. If late positive-going components are indices of integration, for the P600 into sentence structure and for the LFP into the sentence model, standard English vocabulary and sentence structure skills appear to facilitate both types of integration, at least in sentences constructed in standard English dialect. Overall, for bidialectals, the age of acquiring the target (standard) dialect appears to influence prediction while standard dialect vocabulary and syntactic skills affect patterns of sentence and discourse integration. Among these highly proficient native speakers of English, dialectal variation in language experience is thus associated with differential patterns in sentence processing. The lack of an N400 or P600 response to anomalous grammatical forms is considered a hallmark of novice language learners, as they are still in the process of acquiring sensitivity to 'correct' grammatical structures. However, in the case of bidialectals, this ERP response appears to be, not a neural signature of lack of proficiency, but rather one of experience with more than one language variety. As with the heritage speaker examples, a single information processing model, particularly one based on monodialectal, monolingual assumptions of attainment, does not fit well with proficient language processing in bidialectal speakers.

*Cognitive models and complexity at the **process** level*

Diverse language or dialectal experiences present a challenge for a unifying model explaining the cognitive architecture modulated by these experiences. Another challenge for such models arises at the process level. In particular, models that characterize language processing at the word level where semantic retrieval and cognitive control processes may appear more distinct, encounter challenges in accounting for the integrated, higher order nature of language use at the sentence and discourse levels. Human language at these larger grained levels of

analysis involves prediction at multiple levels that takes into account contextual clues to create broad representations or schema for meaning (Altmann & Kamide, 1999; Kuperberg & Jaeger, 2016; Pickering & Gambi, 2018) with a range of experiential factors contributing to how the human brain generates predictions and constructs meaning.

For example, much of what is currently known about neural correlates of language processing has emerged from research with monolingual or native speakers (Meyer & Friederici, 2016 for a review), revealing a core functional network for language processing primarily organized around left-lateralized temporal and posterior frontal areas (Friederici, 2012; Hagoort, 2019; Skeide & Friederici, 2016, for reviews). Although much of the work elucidating this network arises from word-level and highly controlled sentence-level studies, researchers are increasingly tackling the 'messy' nature of naturalistic language processing. Naturalistic speech provides a rich communicative context which allows for both nuance and variability, and as such, are processed quite differently from isolated word or sentence stimuli (Bhattachali et al., 2019; Brennan et al., 2012; Brennan et al., 2016; Hamilton & Huth, 2018; Shain et al., 2020; Willems et al., 2016). Other studies using naturalistic written text (Henderson et al., 2016), reading fiction paragraphs and a practice reading assessment and naturalistic audio stimuli with brain imaging measures such as MEG/EEG (Brennan & Pylkkänen, 2017) and intracranial EEG (Nelson et al., 2017) have produced similarly variable results, implicating both core left hemisphere language and control structures.

For bilinguals, fMRI findings indicate that both semantic and wider language and control networks appear to largely overlap across a bilingual's languages (Hernández et al., 2007; Luke et al., 2002; Perani et al., 1998; Scherer et al., 2012; Van de Putte et al., 2017). Using word and sentence paradigms, neuroimaging research has found that the most common differences in language processing across bilinguals' L1 and L2 are overall more quantitative than qualitative, with bilinguals displaying either greater or lesser activation of the same language network regions, and also displaying more bilateral activation of homologous brain regions associated with language processing when compared to monolinguals, particularly the inferior frontal and medial temporal lobes (Del Maschio & Abutalebi, 2018; Kotz, 2009; Roncaglia-Denissen & Kotz, 2016; Sulpizio et al., 2020). These heterogeneous results support adaptive models of bilingual language processing such as Green & Abutalebi's (2013) Adaptive Control Hypothesis,

which proposes that the demands of different linguistic environments require different neural adaptations in order to successfully manage the use of more than one language.

Complexity at the process level with sentence and discourse level language may also interact with person level complexity. The variability from neuroimaging studies of language and syntactic network activation described above may be related to a range of language experience factors such as age, proficiency, and context of language acquisition (Luk & Bialystok, 2013). In adults, differences in processing across languages have been found to be moderated by proficiency (Dodel et al., 2005; Golestani et al., 2006; Tettamanti et al., 2002), with higher proficiency in the L2 associated with more native-like neural activation (Sakai et al., 2004), as well as by onset age of L2 acquisition (Berken et al., 2017; Golestani et al., 2006; Hernández et al., 2007; Ou et al., 2020; Tatsuno & Sakai, 2005; Wartenburger et al., 2003). In addition to individual-level factors, language-level characteristics such as the degree of syntactic similarity between bilinguals' two languages has been associated with differences in neural signatures of linguistic processing, for example in word order (Jeong et al., 2007) and relative clause embedding (Suh et al., 2007; Tolentino & Tokowicz, 2011). Finally, processing in L2 has been characterized by greater activation of language and cognitive control regions and networks as compared to L1 language comprehension (Calabria et al., 2018; Gurunandan et al., 2020; Mouthon et al., 2020; Seo et al., 2018; Sulpizio et al., 2020; Wu et al., 2019).

We have done some preliminary work examining neural correlates of syntactic processing of naturalistic discourse, particularly in relation to expository lessons such as those bilingual adolescents might encounter in school settings. L1-English and L1-Spanish/L2-English- speaking adolescent middle schoolers watched and listened to an expository video lesson on a science topic reflective of grade-level science standards. In network connectivity analysis, we found an overall qualitative pattern of greater bilateral functional connectivity in Spanish-English bilinguals as compared to L1 English speakers from syntax-related regions to whole brain clusters in homologous and control regions. Reflecting the prior literature, the engagement of brain regions employed in language comprehension was not as reflective of language status as was the degree of connection among those functional regions.

Developments in cognitive neuroscience and in bilingualism research more generally have thus highlighted, at least in the realm of language, the wide range of human adaptability and variability in the language system. While Bialystok envisioned her theoretical model of language

learning in the 1970's as flexible and empirically verifiable, this model was ultimately intended to become a definitive structure for all individuals describing the acquisition and structuring of discrete language representations and rules leading to (ideally) native-like attainment of a second language. However, the heterogeneity and complexity of human communication as a dynamic predictive process underpinned by varied computational networks ultimately reveals the tension between Bialystok's initial theoretical enterprise and acknowledgement of variability and complexity in Bialystok's early oeuvre.

From early foundations to new directions

Both in describing the complexity of bilingual experience and of language processing, the person and process strands of research in Bialystok's early work have thus grown far beyond their initial conceptualization. The seismic shift that Bialystok brought to bilingualism research in the late 1970's moved the field from the descriptive study of categorical stages in language development to a rigorous experimental enterprise in psychology by characterizing the continuum of bilingual experience, distinguishing bilingual language from yet connecting it to control and access to language, and setting forth a theoretical model that could separate language knowledge and cognitive processes. Bialystok's insights, begun as comparisons between immersion and classroom learning of a second language, created the possibility for a later explosion of bilingualism research that took into account the complexity of bilingual experience and was supported by the rigor of analytic models and methods.

Building on the conception of bilingual language experience as a complex continuum, recent work on linguistic diversity, as we have exemplified in studies of heritage and bidialectal speakers, has moved beyond teleological models of ultimate native-like attainment to descriptions of diverse and systematic language practices in their own right. Similarly, building on early information processing models, new understandings of predictive processing, network neuroscience, and social network factors such as entropy among communicative partners (Gullifer & Titone, 2020) have moved beyond the separation of language and cognition as bottom-up stimulus and top-down control. As decontextualized information processing models of human activity are increasingly supplemented by research into contextualized, naturalistic language made possible by technological advances in computational and network neuroscience, a

more holistic picture of human language processing in complex, naturalistic contexts seeks to once again unite language representation and language control research.

The discipline of bilingualism research has thus evolved from Bialystok's early bilingual-monolingual comparisons and positivist, process-heavy approach to an approach that seeks to account for diversity in language experience. Whether a post-positivist approach using varied and approximate measurements of bilingual experience (e.g., entropy, Gullifer & Titone, 2020), a critical approach drawn from sociolinguist theory (López et al., 2021), or a constructivist lens emphasizing, not stage theories, but contextual variation in language processing systems (Bialystok, 2021). However, wherever the field of bilingualism research turns, Bialystok's signature will remain. From her first publications in 1978, Bialystok has called for attention to the importance of recognizing the diversity and continuity of language, to the need for analytic models and procedures to address this diversity, to the need for methodological rigor, and to the importance of interdisciplinary work. These principles, all contained within Bialystok's first paper articulating her self-identified most significant scientific contribution, *A Theoretical model of second language learning* (Bialystok, 1978), will carry us far.

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