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Harnessing the bilingual descent down the mountain of life: Charting novel paths for Cognitive and Brain Reserves research

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Abstract

Evidence from various empirical study types have converged to show bilingualism's potential for serving as a cognitive and brain reserves contributor. In this article, I contextualize, frame the need for and offer some expanding questions in this endeavor, inclusive of empirical pathways to address them. While the set of variables and questions discussed herein are definitively incomplete, they embody a good starting point for shaping future directions in research that considers the role bilingual language engagement can have for the developing mind and brain, inclusive of how various, non-linear factors impact the descent bilinguals of various types take down the proverbial mountain of life.

Introduction

If we view life as a mountain and our lifespans as a climb, anecdotal observation alone leads to what developmental and aging sciences have documented and endeavored to explain for quite some time: the journey is flanked by periods where our minds and bodies are not – as nature would intend – at their prime. In children, the process of development towards the peak is one of patient, yet exciting anticipation. Barring pathology and notwithstanding individual genetic and important (inequitable) environmental differences, all children mature to a state where their bodies and cognitive functions are gradually more developed than the days, months and years before. After individuals reach the pinnacle and surpass a plateaued stretch, one naturally commences the processes of physical and cognitive descent over the course of the AGING PROCESS. While the early and later years of life share overlapping signs of off-peak abilities, they are not equal[1]. As the youth ascend towards cognitive and physical crescendos, their bodies, including the brain, undergo vital physical development in parallel with the expanding of social and family networks, the attaining of independence, the experiencing of (more easily) high degrees of mental stimulation and more. Conversely, having left the heights behind, aging adults progressively go through a reversal of sorts: their fully developed bodies and minds atrophy while social networks, mental activities and eventually independence decrease as a function of various milestones associated with increasing age. The adult's off-peak state is, thus, distinguished by tradeoffs from a unique vantage point of experience and its resulting heuristic proficiency.

Of particular interest herein is a subset of consequences the descent has for the mind/brain specifically. COGNITIVE AGING (CA) refers to the naturally occurring (i.e., it is definitively not a disease), progressive attenuation of cognitive abilities (e.g., memory, decision making, attention) and deterioration of the physical brain (structure and function) over the lifespan (Salthouse, 2004, 2019). While CA is a lifelong process, our focus herein is primarily on the part that exists within later years of life. To experience *CA* for as long as possible, is simultaneously a privilege and misfortune. After all, to do so means one has survived the gauntlet of life that paves the path to the top of the proverbial mountain and are well engaged with the ups and downs of the descending journey. Moreover, for a majority of older aged people, *CA* is not excessively cumbersome or infringing (e.g., Dumas, 2015; Harada et al., 2013; Salthouse, 2019). While one notices changes in mental sharpness, the extent to which they drastically alter one's lifestyle is typically not severe insofar as they do not outpace other natural progressive declines with the aging body overall (e.g., mobility issues, decline in sight/hearing).

While normal *CA* is inevitable, it is not uniform. To begin with, generally speaking, *CA* effects in older age manifest differentially across distinct cognitive abilities. For older adults affected more by *CA*, there is significant individual variation in timing onset, progressivity rate and severity of symptoms (Stern, 2002; Tucker-Drob, 2019). In the case that particular symptoms of *CA* present earlier and/or more severely than normal, one has reason for concern. Such symptoms can find their roots in various types of atypical neurodegeneration, either with or without co-morbidity of other primary neurological disorders such as Parkinson's and

Huntington's diseases (Aarsland et al., 2005; Martinez-Horta et al., 2020). Minor, yet abnormal cognitive senescence is often diagnosed as MILD COGNITIVE IMPAIRMENT (MCI), which may or may not develop into dementia later on. In the case of severe symptoms, various types of dementias are diagnosed as the source cause. Even still, for severe *CA* associated with pathological neurodegeneration there is still considerable variation in timing onset, progressivity rate and severity of symptoms. Understanding how and why these variations come to be is the topic of much research and of particular interest here: what variables contribute to why some people have later and/or less *CA* symptoms when increasing age is controlled for?

Neuroscience, cognitive/psychological science, genetics, gerontology, exercise science, nutrition science among many other disciplines have addressed questions of the above type. Amongst other important insights, accumulating evidence points in the following directions: (i) individual differences in how normal and pathological *CA* manifest are not random and (ii) various (naturally occurring) lifestyle enrichment factors have significant impact on and explanatory power for how symptoms play out. Couched within the cognitive and brain reserves hypotheses (Stern, 2002, 2009; Stern et al., 2020) – the idea that over the course of life individuals can differentially accrue via life-style enrichment experiences natural protection against loss of brain structure (brain reserve, BR) and/or cognitive function (cognitive reserve, CR) related to aging or disease – the present paper zooms in on one particular lifestyle factor: BILINGUALISM[2].

At present, a critical mass of research shows, at least under conditions of active multilingual language engagement and/or over the cognitively demanding process of additional language learning itself, the juggling of more than one language in a single mind can have consequences for various domains of cognition and the brain structures and networks that subserve them (see DeLuca et al., 2020; Grundy, 2020; Pliatsikas, 2019, 2020; Prat et al., 2019). The leading hypotheses for these effects link them to the (degree of) demands placed on cognitive-processing systems needed to manage more than one language (see Bialystok, 2017; Bialystok & Craik, 2022 for review). If so, bilingualism has all the hallmarks of a potential cognitive reserve (CR) and brain reserve (BR) contributor, which research with elderly populations corroborates (e.g., Anderson et al., 2021; Bialystok, 2021; Calvo et al., 2016, 2023a; Gallo et al., 2022a; Guzmán-Vélez & Tranel, 2015; Voits et al., 2022a). Although for context we will go through the main arguments and constructs from the relevant literatures in greater detail below, the purpose and ultimate value of the present paper are definitively not to repeat or merely highlight why bilingualism is likely to serve as a CR and BR contributor. Rather, the goal is to unpack important considerations of investigating bilingualism as a potential reserve contributor, specifically highlighting various new directions for empirical research working with older bilinguals. In doing so, we will primarily tackle why and precisely how leveraging/juxtaposing a wider, untapped spectrum of naturally occurring, dynamic laboratories of bilingualism as they exist differentially in the real world of older adults globally can open up novel questions while contributing to better addressing and answering existing ones in the bilingualism and aging literature. Consequentially, additional insights regarding the very nature of CR and BR more generally will materialize.

We will do the above by articulating questions that give rise to new directions in empirical and longitudinal research programs working with older bilinguals. The argument will be made that of the known environmental factors for reserve accrual, the dynamic nature of BILINGUALISM, when operationalized and capitalized on with appropriate nuance and care, provides the requisite variation essential for: (i) teasing out how language experience contributes independently to and/or interacts with other factors for CR and BR accrual, (ii) revealing novel insights into the very constructs of CR and BR themselves and (iii) advancements specifically in the neurocognitive study of bilingualism and aging, if not the neurocognition of bilingualism more generally.

The argumentation will be predicated on the considerable spectrum of (circumstances leading to) changes in bilingual engagement behavior (linguistic exposure and usage patterns) that naturally exists globally (and locally) in the latter years of life for some (crucially not all) bilingual communities and the subgroups and individuals that comprise them. Exploiting and manipulating to our advantage the heterogeneity of these naturally occurring shifts in bilingual usage/engagement "maintenance" specifically in older age when reserve deposits begin to be used, on the scale that already exists, renders bilingualism truly special as a testing ground. The potential hyperbole of such a claim is tempered by the fact that well over half the world's population is multilingual (De Houwer, 2021; Grosjean, 1982; Rothman et al., 2019). While the ratio/distribution of (functional) monolinguals to multilinguals comply with geographic and sociopolitical tendencies, there is no corner of the inhabited earth where multilingualism is absent. Its distribution defies not only geography, but class, age, sex/gender and wealth. As a result, arguments can be made that bilingualism is uniquely equitable compared to other lifestyle reserve contributor factors, which otherwise can be highly co-linear with high socio-economic status (Gallo et al., 2022a). And yet, despite the ubiquity and favorable, equitable coverage of multilingualism, no two multilingual contexts are exactly the same. Its diversity and variation, useful empirical ingredients, as well as the factors underlying them are abundant, definable and measurable.

What is the global reality of Aging?

Since the later part of the 1800s, many countries have seen over a doubling of their 65 years-and-older populations (Kinsella & He, 2009). According to a World Health Organization 2021 report, in 2020 there was roughly 1 billion people over the age of 60 globally. By 2050, this number is expected to more than double. Between 2020-2050, the number of individuals over the age of 80 are expected to triple, reaching nearly half a billion. Not only is the global population increasing, but current gains in life expectancy are outpacing the already upward trends in population growth. To be sure, this reality marks progress on many fronts for science and humanity. However, it also entails the three "c"s: real societal and personal COSTS, CONCERNS and CHALLENGES, not least because the resources required to functionally, ethically and compassionately manage increased age on such a scale in our societies – let alone at the individual (family) level – are staggering.

While neurodegeneration is not the only inherent health-related concern of aging, the economic and personal reality of it and its ubiquity make it stand out. The World Health Organization 2021 report claims that more than 55 million adults currently suffer from various types of dementia worldwide. This report also suggests that year-on-year 10 million new cases of dementia are expected. Global estimates in 2016 suggested then that the total economic costs of caring for elderly people with dementia was approaching the trillion dollar mark (Xu et al., 2017). The Xu

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et al. systematic review indicated that by 2017 the average cost in Europe had risen to just over €32,500 per case. For sake of comparison, the average annual median equivalized income in the EU-27 in 2018 was just under €17,000 (even at the top end of the range, Luxembourg, it was just over €32,500).

The economic burden of cognitive decline is undeniable and will only continue to grow. But not all parts of the world are equally positioned. According to the same World Health Organization report, of the 55 million cases of dementia globally, roughly 60% reside in low and middle-income countries. And yet, 74% of the costs related to care occur in high-income countries. Even if economic resources were boundless, never mind equitably distributed, societies would still need to confront serious limitations with respect to what the current state of health science offers for quality-of-life issues in our senior populations. Indeed, current pharmacological treatments for many cognitive/ neurodegeneration ailments are scarce and inadequate (Briggs et al., 2016; Fish et al., 2019). For example, the best available drug treatments for Alzheimer's disease, effective at an efficacy rate barely scratching 50%, compensate for cognitive decline symptoms on the order of months.

While atypical pathological neurodegeneration is and should remain a primary concern, one should not ignore what the three Cs (costs, concerns and challenges) bring to bear for normal *CA*. After all, estimates indicate that by 2050 there will be at least 2 billion people in the thick of either typical or atypical *CA*. It seems that presently, the best prevention/treatment options for symptom onset/severity for pathological and typical *CA* available are lifestyle enrichment factors that stretch neuroplasticity, such as physical exercise, healthy diet and a range of activities/therapies that challenge, strain and thus train the brain (Klimova et al., 2016, 2017; Teixeira et al., 2012; Wang et al., 2020). What role does/ can bilingualism play in this space?

Reserves: How does our lifestyle contribute to them and what role do they play in cognitive aging?

Behaviorally, normal *CA* is associated with a decrease in overall processing speed, certain types of memory (e.g., short term and episodic), language, visuospatial and executive functions (EFs) and is marked by significant individual variation in cognitive performance (Salthouse, 2000, 2004, 2019). At the neural level, *CA* is perhaps most clearly identifiable in anatomical changes in gray matter (GM) and white matter (WM) integrity, particularly in the prefrontal cortex and hippocampus, paired with decreased efficiency (i.e., increased requirements of implicated networks) in task performance (e.g., Farokhian et al., 2017; MacPherson & Cox, 2017; Persson et al., 2006). Symptomatically at the behavioral level and neurologically, Mild Cognitive Impairment (MCI) and dementias of various types associate similarly, the main differences relating to progression rate, pervasiveness, severity and specificity of cognitive impairments and neurological damage as well as the potential for various bio/neuro-markers for (predictive) diagnosis. Among other ways, normal *CA* and related clinical pathologies can be assessed at the level of functional neural connectivity, the integrated relationship between separated brain regions, as measured by Resting State EEG/ MEG (RS-EEG; Babiloni et al., 2018; Fleck et al., 2017) and/or on-task performance with EEG/MEG (Jauny et al., 2022; Miraglia et al., 2017; Polich, 1997). For example, in older age, greater mean coherence (neural connectivity) in RS-EEG at the individual level correlates with higher levels of cognitive/brain reserves (Fleck et al., 2017). In the present context, one wonders under what degrees of bilingual experience does better (preserved) mean coherence obtain (Bice et al., 2020; Calvo et al., 2023b; Pereira Soares et al., 2021) and, if so, how does that translate to older age?

In the context of the discussions herein, we can understand Cognitive Reserve (CR) as a protective mechanism related to efficient connectivity among the neural circuits supporting sustained cognitive function following damage to the physical brain associated with age, injury, disease or a combination thereof. Similarly, Brain Reserve (BR) refers to the protective potential of anatomical features such as neuronal density and synaptic connectivity. According to the reserve hypothesis (see Stern et al., 2020 for review), using accrued reserves in later age provides compensation for natural degenerative and neuropathological damage, accounting for significant (and often highly beneficial) individual variation in onset and degree of normal *CA*, MCI, and dementia, despite neurodegenerative changes that are underlyingly similar in nature and extent (Perneczky et al., 2019; Petrosini et al., 2009; Villeneuve, 2019). How do these reserves build up? While genetic factors can be determinants of individual differences, research shows that lifestyle factors such as higher levels/more years of education, healthy nutrition, occupational attainment, engagement with leisure activities that promote cognitive and/or physical excursion correlate in older age to degree of cognitive and brain reserves (Stern et al., 2020) – for example, greater RS-EEG mean coherence as referenced above (e.g., Fleck et al., 2017).

Why should lifestyle factors matter? Let us unpack how this process is hypothesized to work using a factor with robust predictive validity for augmented resilience to the symptoms of *CA* and clinical dementia: Physical Exercise (PE) (e.g., Campbell et al., 2019; Yaffe et al., 2009). Conceptually, how this works is not qualitatively different from the much more commonly discussed case of cardiovascular health. PE renders the heart muscle efficient in doing its intended job for longer: pushing out more blood, which lowers resting beat-rate and keeps blood pressure optimally regulated. Similarly, PE is argued to be deterministic for structural changes in the brain such as increased gray matter volume in frontal and hippocampal regions (e.g., Erickson et al., 2014) and reduced gray and white matter degradation (Burzynska et al., 2014) in older populations. Like the case of the heart, engagement in good-measured PE strains and trains the cerebrovascular system. This, in turn, conditions benefits on glucose and lipid metabolism carrying "food" to the brain (Mandolesi et al., 2018), leaving reserve deposits over time that later correlate to more favorable onsets, progression and symptom severity for *CA* and neurodegeneration.

Can bilingualism contribute to reserve accrual?

In this section, we contextualize and summarize the evidence supporting the position that, like PE, engagement with the (mundane) activities required for bilingual language control demands, at least under specific intensities, provides stretched neuroplasticity related to CR and BR accrual. To begin with, many studies have shown older bilinguals outperform monolinguals (often better than young bilinguals) on cognitive control and memory tasks, behaviorally and at the brain level (e.g., Bialystok et al., 2004; Grant et al., 2014; Kousaie & Phillips, 2017). Older bilinguals also show better preserved brain structure across white matter and grey matter (Perani & Abutalebi, 2015; Pliatsikas, 2020) increasingly as a function of increased bilingual

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engagement (DeLuca & Voits, 2022), lower activation while performing executive control tasks (Gold et al., 2013), superior resting state functional connectivity, suggesting increased neural efficiency (Pliatsikas & Luk, 2016) and degree of bilingual engagement correlating with hippocampal adaptations in typical aging and with those diagnosed with MCI (Voits et al., 2022b, 2023). Several recent meta-analyses bringing together relevant studies from the past two decades point in the same direction: bilingualism correlates with later onset of symptoms and, thus, diagnosis of dementia by as much as 5-7 years relative to comparable monolinguals (Anderson et al., 2020; Brini et al., 2020, although other factors can mitigate such as SES indicators, e.g., Gollan et al., 2011). A recent paper worthy of specific mention cleverly matched brain pathology via MRI scanning across bilinguals and monolinguals, effectively showing that brain-matched older monolinguals display significantly more behavioral deficiencies in cognitive functioning (Berkes et al., 2021). Another noteworthy recent study focused on conversion rates from MCI to Alzheimer's Disease (AD), showing that while bilinguals attending a memory clinic are older than monolinguals when diagnosed with MCI by a differential of 3 years, bilinguals have an increased MCI-to-AD conversion rate of a year (Berkes et al., 2020). This is not surprising when one considers that bilingualism (any reserve contributor factor for that matter) does not stop or necessarily slow down the actual neurological erosion of degenerative disorders, but rather masks/compensates for the behavioral symptoms that lead to diagnosis until a breaking point. In any case, all of these observations from the literature – and more – lead not only to the conclusion that bilingualism can have a particularly strong effect on the aging mind/brain, but that it serves as a significant CR and BR contributor.

How does bilingualism contribute to the building up of reserves in the brain? While the precise mechanisms are not entirely clear – as is the case for all proposed CR and BR lifestyle enrichment factors – a crucial, shared commonality with other potential contributor factors is the cognitively demanding nature of bilingualism. The presence of more than one language introduces competition in several overlapping cognitive systems (Green & Abutalebi, 2013; Jared & Kroll, 2001; Marian & Spivey, 2003; Spivey & Marian, 1999). As all languages are simultaneously activated in the mind, even when the context calls for a unilingual mode, there is a pressing and ubiquitous need to regulate interference. Bilingualism, especially under certain conditions, requires constant and often unpredictable selection between the two (or more) languages (Abutalebi & Green, 2016). After all, one could be using language X at any given time, but someone associated with language Y unexpectedly enters a room where instantaneous switching becomes necessary. The resolution of this competition requires increased engagement of cognitive control functions, under the more general umbrella of attention, including inhibition, particular types of memory, monitoring and updating for successful communication to take place. The degree to which one's circumstances requires dynamic multilingual engagement is thought to "train" related cognitive skills and brain networks, making them more efficient. Research such as that presented above suggests that these effects extend beyond language control to domain-general cognition and that adaptations in cognition are supported by corresponding changes in the brain, specifically brain networks and areas underlying cognitive control functions that overlap with language control. Crucially, the functions and brain regions argued to be enhanced by bilingualism over the lifespan (Pliatsikas, 2019) are not random, but largely overlap with those that decline due to *CA*, MCI, and dementia (Voits et al., 2020).

How can we move forward with novel direction?

As we have seen above, while evidence from complimentary angles converges and is convincing, it is gathered and framed to effectively serve the singular question of whether or not bilingualism can be considered a genuine CR and BR contributor. There are conspiring reasons for this. To begin with, the original question had to be asked before any others could make sense. Only by having obtained the available evidence in pursuit of addressing the original question is the foundation now set for asking further ones. Moreover, a sizable portion of the available data used to address the basic question is unnuanced with respect to how bilingualism is qualified/quantified at the intersection of at least two axioms: (a) degree of engagement with bilingualism over (b) the time domain. For some study types, there is simply no way to (have) avoid(ed) this, effectively delimiting the possible set of askable questions from the outset. For example, in cohort studies showing that bilinguals, over monolinguals, are diagnosed with dementia with as much as 5-7 years delay, the data used are from preexisting medical records from which one is lucky to have had any indication of mono- vs. bilingual status at all. In many cases, this dichotomous categorization is all that is available in the relevant sense, thus essentially forcing the formation of broad groups for relatively simple statistical comparisons. And still, the fact that bilingualism emerges with good predictive validity in so many of these studies across broad geographic and sociodemographic coverage is all the more impressive.

Having a relatively unnuanced monolingualism vs. bilingualism comparison is not always a forced choice of the data at hand. And yet, even in purposefully designed empirical studies, a more-or-less dichotomous comparison still dominates the bilingualism and (neurocognitive) aging literature, as true of bilingualism studies in general. Given argumentation for why simple monolingual vs. bilingual comparisons are potentially problematic for bilingualism research in general (e.g., De Houwer, 2023; Rothman et al., 2023) and especially insufficient for questions related to neurocognition by failing to consider the impact of individual differences in bilingual experience (e.g., DeLuca et al., 2019; Titone & Tiv, 2022), it seems incongruous to not adapt accordingly in the aging and bilingualism literature. To be fair and clear, it should not be understood from the present argumentation that monolingual-to-bilingual aggregate comparisons, even relatively simplistic ones depending on the question, have no use in the present space. The majority of the studies reviewed throughout this article thus far speak well to the contrary. Rather, a better framing is to ask what the field has been missing out on by not having pursued alternatives. In other words, what questions have not yet been properly framed/addressed as a result?

While research clearly shows that bilingualism can correlate to behavioral and neurological exponents understood as embodiments of CR and BR, in my view, there is very little from the existing literature that speaks to the relative weighting of (real world diversity in) bilingual experiences themselves in relation to CR and BR. This means that what could be a mutually beneficial, bidirectional road has essentially been a one-way highway: bilingualism research couched within the CR and BR reserve hypothesis has not contributed much back to the theory from which it

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draws, despite potentially being its largest testing ground. For those primarily interested in bilingualism and aging, this also means that we know much less about HOW bilingualism actually functions for CR and BR accrual and subsequent deployment then we ought to.

To begin to fill some of the gaps of missed opportunities, several questions – not a complete list to be sure – immediately come to mind. To start, it seems worth considering the following interrelated questions: WHAT IS THE NATURE OF RESERVE ACCRUAL IN THE SHORTER TERM – FOR EXAMPLE, WHEN LANGUAGE LEARNING IS USED AS AN INTERVENTION IN THE OLDER AGE? and (how) DOES IT DIFFER WHEN OLDER MONOLINGUALS ARE FIRST INTRODUCED TO BILINGUALISM (TRUE L2 LEARNING IN THE ELDERLY) VIA LANGUAGE LEARNING AS COMPARED TO WHEN PREEXISTING OLDER BILINGUALS LEARN ADDITIONAL LANGUAGES? Although, space does not permit a deep dive here, given the theoretical and practical promise of older age language learning interventions in the general topical space of the present discussion and its emerging prominence in the empirical landscape (Klimova, 2018), a few thoughts are befitting.

Research already exists showing that novel language learning in older ages changes the structure of the brain (Li et al., 2014; Nilsson et al., 2021; Schlegel et al., 2012), pondering/proposing it as a potential reserve building intervention (Antoniou et al., 2013; Kliesch et al., 2022; Klimova, 2018; Wong et al., 2019). And yet, such research mainly addresses the "can X result in Y" question, offering little insights on the nature of bilingual-induced reserve accrual itself. For example, what do such changes tell us about any specificity of later language learning over the learning of anything else that involves complex cognitive processing? Are correlations merely a reflection of learning that happens to be targeted with language or is there something related to introducing/augmenting bilingualism specifically? At first glance, such a query can (and has been attempted to) be controlled for via the inclusion of comparison groups with non-linguistic, but equally demanding cognitive training. And while doing so offers better control for answering the "can X result in Y" question, it only partially addresses the spirit of actual expansion questions we have posed above.

Of course, no one is suggesting that bilingualism or language specifically has any special characteristic as a cognitive flexor accruing BR and CR over other potential lifestyle factors. And yet, things related to language are not inconsequential, specifically the degree of dual language engagement in the usage tug-of-war of the available languages OVER TIME and its ubiquity in the real world of so many. This consequential part of bilingualism is greatly reduced, if not removed from the learning-as-intervention empiricism. And so, while it is incredibly promising that language learning in later life shows signs of neurological adaptation in similar areas to real world bilingualism in its various forms, it cannot be taken for granted that what seems to be similar CR and BR in both cases is in fact the same. After all, what can be captured via language learning-as-intervention studies could only ever be a sub-part of the CR and BR accrual potential of the case of bilingualism in the "wild" over time, that corresponds with the expansion phase – where the brain adapts to handle the demands presented by the learning context itself – of the Dynamic Restructuring Model (DRM, Pliatsikas, 2020). For particular questions, that is enough. Ultimately, however, we are interested in understanding bilingual induced CR and BR more broadly, which includes how they come to manifest and are sustained/used after the intensity of language learning itself ceases. That is, what can studying the longevity of bilingualism tell us in stages the DRM describes as points where normalization of brain matter or even reductions are expected, notwithstanding maintained or enhanced corresponding cognitive performance, a CR sign of efficiency. While existing studies have independent theoretical and practical value, it is not clear how they bring us closer to a more complete, nuanced picture of the mechanisms at play in bilingualism neurocognition *per se,* much less a better understanding of how bilingualism research contributes back to the construct validity of CR and BR more specifically.

Let us consider and, in fact, dedicate the remaining space to the following set of questions then: (1) What is the independent value of bilingualism in CR and BR accrual, that is, factoring out other lifestyle enrichment contributions? (2) How do the patterns of bilingual engagement, more and less stable, over the lifespan relate to availability of reserve "funds" later in life? and (3) How do changes – gradual and abrupt – specifically in the later years of life affect the sustained availability and deployment of reserves in the older age? As should be evident, these questions differ from previous ones in two important ways. First, they do not seek nor contribute to querying if bilingualism is a CR and BR contributor. Rather, they start from the premise that it can be. Secondly, these questions are apt, if not designed, to shed light on the mechanistic aspects underlying the interfaces between bilingualism, neurocognition and aging as well as shedding some unique light on the construct nature of CR and BR. What remains, then, is to provide, question by question, better context for how each pushes the general program in novel directions, underscoring what is gained by doing so and how one can begin to do it.

With Question 1 in mind, it must be acknowledged that no lifestyle enrichment factor exists in a vacuum. In fact, some are highly correlated. For example, a person who engages in high degrees of exercise is more likely to eat a healthier diet, have a better sleep balance, and, on average come from higher SES. And yet, variation in how even these correlated factors present at the individual level are sufficient to tease them apart in carefully designed research. While some nods to bilingualism potentially being a CR and BR contributor can be found in the general cognitive neuroscience literature (typically mere mentions in reviews and white papers – e.g., Stern et al., 2020), bilingualism – least qualitatively nuanced variables that proxy for its degree of engagement/usage patterns – is a factor that is essentially never included as a co-variable in such empirical studies. Alternatively, while studies, review papers and meta-analyses that hone in on the role of bilingualism in the CR and BR space typically review at length research done with other lifestyle enrichment factors, the opposite is true: with few expectations (Gallo et al., 2022b) empirically all other known factors that could be confounded are effectively ignored. As a result, we have no way to know what role, if any, bilingualism might be playing in studies focusing on other lifestyle factors as much as not controlling for these other factors in bilingualism-focused studies compromises determining the unmoderated role bilingualism is actually playing as an independent factor. Given the ubiquity and dynamicity of bilingualism world-wide and how it interacts with the spectra of other lifestyle factors, the above scenario means that some level of undesirable noise is floating around un(der)acknowledged in many, if not most available studies from all literatures working on CR and BR. This makes it all the more essential to do two things: (a) understand the moderated relationship between clusters of lifestyle enrichment

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factors, including bilingualism and (b) support research that can tease their independence apart meaningfully.

Some notable steps in this direction are beginning to emerge of which the Fitness, Aging and Bilingualism (FAB) project lead by Linda Wheeldon in Norway and Katrien Segaert in the UK and a project within our lab, at UiT, the Arctic University of Norway, EEG-Cognitive Aging Project (EEG-CAP) are good examples. EEG-CAP, while measuring bilingualism as a spectrum of experiences, includes a set of measures tapping into individuals' physical exercise, dietary patterns, social networks, general life satisfaction, and a composite proxy for lifetime accrual of CR (engagement in cognitively engaging activities). With the goal of a sample size in the several hundreds (n = approximately 150 presently), the detailed background information pertaining to many life-style factors will be used to unpack individual patterns in brain (rs-EEG and on-task EEG) and behavioral data tapping into various executive functions and different types of memory. Structural equation modelling will be applied to understand the moderative relationships of all these factors. Work like EEG-CAP is not only welcome but introduces new frontiers for expanding questions in bilingualism and aging research as well as bridging it with the cognitive neuroscience of aging more generally.

Addressing question 2 begins to reveal the latent potential for bilingualism to shed specific light on the nature of BR and CR. Using the metaphor of a bank account, the idea here is to utilize the dynamic nature of bilingualism in well-designed empirical studies to understand what types of bank accounts CR and BR represent. But how can one go about testing how more and less stable patterns of bilingual engagement over the lifespan relate to availability of reserve "funds", which, in turn, tells us something about their very nature? I would like to suggest that scenarios of real-world, major shifts in societal bilingualism that have happened over the past few decades present a good place to start. Under scenarios where a society (or major parts of it) was (functionally) bilingual, but no longer is or the opposite – resurgences of societal bilingualism that was (for a period) not supported – cohort studies with now aging adults who lived through periods where major changes out of their control resulted in increasingly less or more societal bilingualism and whose individual engagement with bilingualism shifted or not in parallel – so-called increasers/maintainers vs. attriters – such a complex question can be meaningfully put to test. Let us consider a project I have recently framed with Tom Voits, which seeks to examine older adults in the former Soviet Union republics as a case in point. Take for example, the Latvian society. Prior to the early 1990s, either Russian or Russian/Latvian bilingualism was the expected norm for many decades, reenforced by the necessity of Russian in all domains of the public sphere. While it is true that large sections of the Latvian population still report dominance in Russian, for most Latvian native speakers a dramatic shift linguistically took place in parallel to Latvia's gaining independence in the early 1990s. Rather quickly, Russian was replaced by Latvian in the public sector and with it the need to maintain usage of Russian fell off drastically for many, but not all Latvians and, crucially, the degree of this shift is not absolute but continuous at the measurable individual level. For many in the target age-range of our studies, dramatic shifting will have taken place after having lived as much as 50 plus years in default bilingualism. The degree of Russian loss – from nothing to complete and all points in-between – at the individual level on the scale of hundreds of thousands of people provides both the numbers and diversity needed to capitalize on this reality to test the waters of how degree of maintenance /attrition of bilingual engagement plays out. Our idea, in scenarios of this type, is to do a very similar study in method as described for EEG-CAP. To address question 2, we will take blocks of people currently at three age groups 60-69, 70-79 and 80-89 and develop bespoke questionnaires to augment the battery described for EEG-CAP to tap into their maintenance/ attrition/increase of Russian/Latvian engagement since the early 1990s to begin to understand what role this plays. Doing so will be the first attempt at charting and factoring the ebbs and flows of bilingual language engagement as a proxy for the deterministic role of its dynamicity, on scale and with ecologically valid control. Peeling back the layers of impact degree of bilingual engagement shifting over the lifespan might have, where it naturally ranges from potentially little to dramatic after decades of previous stability, is non-trivial. In the bank account metaphor, such work will offer insights into what types of accounts reserves represent: are they interest bearing, if so, is the interest compounded or simple, do they have caps for deposits and what happens to large deposits made that are not added to at all, added to little or suddenly augmented to over stretches of time?

While research designed around scenarios such as the Latvian one are well-positioned to frame and address Question 2, informing both the reserve hypothesis directly and our own theory internal questions related to CR and BR in the real world of bilingualism, they do not afford the control needed to ask Question 3: How do changes – gradual and abrupt – specifically in the later years of life affect the sustained availability and deployment of reserves in older age? This is so because individual level shifting is motivated and, thus, significantly impacted by an unpredictable event at the societal level where, as time from the precipitating point of sudden changes moves on, there are various implications that result in continuity losses related to other variables making replication of conditions *a priori* impossible. That is, 1991 – the point that Russian changes dramatically in the Latvian landscape – is fixed in time and the pool of participants for such studies is fixed at that point (1991) and limited to those that happened to be there at whatever age one was at that time, having been bilingual under whatever intensity they were for as long as they were at the time. Of course, as each year passes from 1991 the ensuing societal changes and attitudes stemming from that abrupt change can also have an effect and present, today over 30 years (and growing), potential noise for particular questions. These facts can be manipulated advantageously in pursuit of addressing Question 2, but pose obstacles for precisely determining what shifting in older age specifically entails since this would require seemingly replicable conditions from the same fixed point in time of all participants.

So, how can we go about addressing Question 3 then? In our lab here in Norway, we are framing a series of studies that side steps at least some of the issues discussed immediately above by harnessing the almost default status of bilingualism that exists in our country given the presence and status of English for much of the lifetime of our aging population and the very high proficiency in and functional use of it in this population. With nearly a million people over the age of 65 in Norway alone, such a project provides the scale needed to be meaningful. However, Norway's relationship with English is not so unique in that it presents rather similarly in much of Northern Europe – for example, other Nordic countries (Denmark, Sweden, Iceland and Finland) and the Netherlands. Of course, this might also be true in other parts of the world and certainly for

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languages other than English that enjoy nearly universally high proficiency in places where it is not the native language and also has high functional use in the same society. While it is true that Norwegians generally have good English proficiency, the degree to which they use it can range dramatically. In some public and professional sectors, it would not be a stretch to say that English has a similar functional usage pattern to that of Norwegian – e.g., people who work in jobs that are international facing. For example, while Norwegian is clearly the dominant language in our context, many, if not most, of our colleagues at the university use English daily as they engage with the international landscape of many groups. English can be and often is the default language for particular functions. As a result, for native Norwegians in this context, they are not merely extremely proficient in English but they are highly and continuously engaging with English all the time. But what happens when they retire? While their proficiency might be impacted little, their usage patterns might or might not change dramatically. One can imagine that some will hardly ever need to use English again, others will maintain relationships and habits that result in less dramatic changes whereas others might not reduce English engagement at all. We plan to chart this by tracking individuals longitudinally, starting just prior to retirement (providing a baseline) and for 5 years (at least) after. We are able to plan for this well as in Norway – as in much of the region – retirement comes at a predictable age: currently 67. The idea is to again use the battery of tests developed in EEG-CAP iteratively over time, as well as track information related to diagnosis of MCI and potential conversion rate to dementia with such individuals over this 5 year period – longer should funding exist – whereby we can track in real time starting just prior to and onwards from the very point where dramatic change in bilingualism engagement sets in. We will document the individual degree of change in bilingual engagement alongside any changes in other lifestyle enrichment factor behaviors to both tease apart bilingualism from other factors and understand better what change in engagement entails for CR and BR deployment specifically in the very years where it is needed most.

Conclusion

In this article, I have framed the need and potential for expanding questions related to bilingualism and (neurocognitive) aging. While the set of variables and questions discussed are certainly not exhaustive, they constitute a beginning for what should form part of the next frontier in the legacy and value of considering the role bilingual language engagement has for the developing mind and brain, inclusive of how it impacts the descent from the proverbial mountain of life.

Competing interests. The author declares none.

Notes

[1] It is important to offer some clarification with respect to the "mountain" analogy offered herein, inclusive of some terms used in appealing to it metaphorically. This analogy in no way ignores the ebs and flows that exist in development and aging, that is, points in both childhood and in older age that are nonlinear. Rather, the intention is to appeal to what a simple hike on any mountain evidences: mountains in the real world never have perfectly flat inclines and declines—these only exist in cartoonish renderings and/or can seem as such in photos when the offered perspective comes from a vantage point that is significantly zoomed out. In fact, more generally speaking, it is likely that inconsistencies in heralding the relative zoomed perspective of particular bilingualism and neurocognition studies themselves contribute to misunderstandings that circulate through several debates within the field (Leivada et al., 2021, 2023). In any case, the real nature of mountainous climbs and descents entail a series of peaks and valleys, iterative ups and downs taking place along what is otherwise clearly the ascent or the descent. In this sense, the mountain metaphor is apt to capture the actual non-linear reality of cognitive development across the lifespan. In the context of the present article, highlighting this is especially important in keeping with current discourses in aging sciences, which endeavor to inject distance from a an overly simplistic view of aging based on cognitive decline solely and/or comparisons between so-called healthy aging and neurodegenerative pathology first and foremost (Rowe & Kahn, 1997; Schulz & Heckhausen, 1996). The "mountain", is precisely used herein to recognize the descriptive observation that CA includes moments of growth and arrests and that these actually occur throughout the lifespan.

[2] I use the term bilingualism as a catch-all label, intending to cover multilingualism as well. Such a position does not ignore or preclude the possibility that bilingualism and multilingualism could have distinct outcomes for the relevant domains and theoretical issues discussed herein, however, this is largely a question of degree. For ease of exposition and clarity, it is my view that using a single term is better than interchanging them or creating a new one, such as bi-multilingualism. Given that many researchers and especially non-researchers take the term multilingualism to apply only in the case where at least three languages are at play, I opted to use the term bilingual throughout viewing it as more inclusive such that anyone that requires multilingualism to include three languages would know that the present discussion and claims refer also to people for which only two are in play.

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