The Potential for Literacy to Shape Lifelong Cognitive Health

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Abstract

In light of population aging, an understanding of factors that promote lifelong cognitive resilience is urgent. There is considerable evidence that education early in the life span, which promotes the development of literacy skills, leads to cognitive health and longevity, but the ways in which activity engagement in later adulthood affects long-term cognitive health is not well understood. The literature on cognitive training focusing on ability and skill training has not only demonstrated the existence of plasticity into late life but also shows that improvements are very tightly tied to the abilities trained. The rush to apply ability training to promote cognitive health has produced a vibrant "brain training" industry that neglects the very limited evidence for transfer to significant functional outcomes. Recent evidence on the neural substrates of reading, language comprehension, and discourse processing, as well as on the lifelong effects of literacy engagement in special populations, hints that reading may well be a "whole-brain exercise" with the potential to promote cognitive health. Such findings suggest promise for education-based approaches to promote lifelong cognitive health, calling for (a) societal investment in science at the interface of education and health, in particular to understand the mechanisms through which literacy engagement affects mind, brain, and physical health through the life span, and (b) innovation in developing models of life span education.

Keywords

literacy, cognitive aging, cognitive resilience, bilingualism, life span education

Tweet

It is time to treat education and literacy as matters of public health.

Key Points

- Despite the stereotype that aging brings inevitable declines in memory and attention, there is tremendous variability in trajectories of adult cognitive development.
- Evidence is strong that education early in the life span increases longevity and promotes lifelong cognitive health, but there is little understanding of the mechanisms underlying these effects.
- Reading can engender a highly active mental state, and there is increased evidence that sustained literacy practices, which are engendered by education, sculpt mind and brain.
- It is becoming increasingly apparent that education is the foundation for a strong public health policy, which calls for societal investment in (a) basic and applied science to understand the impact of literacy engagement on health, and (b) the development of life span models of education.

Introduction

In terms of average performance, age declines in speed, working memory, reasoning, executive control, and other fluid abilities are well documented. Effect sizes have been estimated to be up to 2 standard deviations (*SD*s) between the ages of 20 and 80 based on cross-sectional differences in common laboratory measures (Salthouse, 2010), and up to 1 *SD* based on within-person change (Schaie, 2005). At the same time, there is considerable evidence for the existence of plasticity throughout the adult life span (Lövdén, Bäckman, Lindenberger, Schaeffer, & Schmiedek, 2010), which contributes to tremendous variability in the patterns of cognitive development (Hertzog, Kramer, Wilson, & Lindenberger, 2008). In fact, many people thrive in later life and maintain deep involvement in work, civic activities, and complex leisure activities (Salthouse, 2012), and there is currently great scientific, as well as practical, interest in the factors that promote cognitive resilience into old age. There is considerable

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evidence that education early in the life span is a predictor of better late-life cognitive health (Stern, 2009) and even increased life expectancy (Kaplan, Spittel, & Zeno, 2014). The mechanisms through which educational experiences 40 or more years earlier can have such far-reaching consequences for cognitive vitality, health, and longevity are not well understood. Some research suggests that the effects of education on cognitive health are mediated by literacy, and that, in fact, literacy is a better predictor of cognition than education, especially with increasing age (Kavé, Amit, Spaiter, & Ben-Ezra, 2012; Manly, Byrd, Touradji, Sanchez, & Stern, 2004; Manly, Jacobs, Touradji, Small, & Stern, 2002; Manly, Touradji, Tang, & Stern, 2003; Sisco et al., 2015).

Consideration of the intersection of lifelong (cognitive) health and literacy is timely. Concerns about an aging tsunami have been articulated in the scholarly literature, policy documents, and the popular press for some time, and we are currently in the midst of a transition to a much older population (United Nations Department of Economic and Social Affairs Population Division, 2013). While the percentage of the world's population aged 60 and above was 12% in 2013 (up from 8% in 1950), the projection is that this will increase to 21% by 2050. Meanwhile, there is growing recognition of a different sort of tidal wave—the large proportion of adults who complete (or discontinue) schooling without reading skills that are adequate to navigate the demands of everyday adult life (National Research Council [NRC], 2012). These adults may be able to recognize words and answer simple questions about information given directly in the text, but they are unable to use the text to reason or solve problems or enjoy immersion into a book. In the United States, about 14% of adults fall into this category, and to varying degrees, this situation replicates worldwide (OECD, 2013). Older individuals are disproportionately represented among low-literacy adults. In this article, we discuss the implications of this perfect storm of events and why it should make us rethink life span engagement in education and literacy as a matter of public health.

In the following sections, we discuss (a) the nature of adult development and aging and what is known about pathways to "aging well" and (b) the nature of language processing and literacy engagement, and evidence for interactive effects with cognition. Based on these bodies of research, we consider why life span education and literacy deserve critical consideration in the science and policy of successful aging.

Cognitive Aging, Reserve, and Resilience

Cognitive aging is characterized by change in two opposing forces (Baltes, Staudinger, & Lindenberger, 1999; Hartshorne & Germine, 2015). On one hand, declines in speed, working memory, attentional control, and fluid abilities, which can be collectively termed *mental mechanics*, are normative and derive largely from senescence-related changes in neurophysiology. On the other hand, knowledge-related processes and *crystallized abilities* tend to show preservation or even growth, peaking in midlife. Note that mechanics and crystallized capacities are theoretical constructs that are relatively straightforward to distinguish in the laboratory, but there are very few intellectual demands in everyday life that rely exclusively on one or the other; rather, cognition in the ecology in which it is used depends on some balance of these two forces. The use of mechanics predominates when the situation is novel so that one cannot depend on knowledge to recognize coherent patterns in the environment or when there are demands for holding information in mind to solve problems. The use of crystallized capacities predominates in familiar situations in which mental computations are not required or are well learned so as to be automatic. Different people might use different balances of mechanics and crystallized ability on the same tasks. For example, for someone who had never been on a subway before, deciphering the patterns on the London subway map and timetable might be heavily reliant on fluid abilities, but someone from Washington who routinely uses the Metro system might find navigating the London subway relatively easy because that knowledge would render the patterns more apparent. Generally, learning new things is supported by both fluid and crystallized capacities, and there is evidence that knowledge can offset fluid ability declines (Ackerman, 2008; Beier & Ackerman, 2005; Chin et al., 2015; Payne, Gao, Noh, Anderson, & Stine-Morrow, 2012).

In spite of normative trends, trajectories in both these domains of cognition are highly variable across individuals, and the factors that contribute to this variability are numerous and interact through the life span to shape intellectual development, so that ultimately cognitive resilience is a lifelong process (Stine-Morrow & Chui, 2012). Knowledge-based growth is a consequence of long-term investment in activities that are consonant with preferences, interests, and abilities (Ackerman & Rolfhus, 1999; Stanovich, West, & Harrison, 1995). Differentiated development in mechanics is much less well understood. Good health and fitness contribute to preserved mechanics, with experimental work showing that physical exercise that improves fitness also enhances fluid abilities, like executive control (Voss, Vivar, Kramer, & van Praag, 2013). Education early in the life span, as noted above, produces demonstrated benefits for late-life cognition (Stern, 2009) and mortality (Kaplan et al., 2014). Of particular interest here, nevertheless, is how lifelong activities contribute to individual variations in cognitive aging. One explanation is *cognitive reserve* (e.g., Stern, 2009), the idea that intellectual activity early on capitalizes on the heighted neural plasticity of early life span development to (a) knit more complex neural networks and (b) develop habits of mental engagement that predispose the individual to continue activities so as to promote this process. This cognitive reserve, then, serves as a buffer against late-life pathology because there are alternative and redundant routes for processing with age- and pathology-related neurodegeneration. In fact, autopsies tend to show that for individuals matched in cognitive functioning before death, the brains of more highly educated people show more evidence of neuropathology than those of less well-educated people (Stern, 2009), consistent with the notion that education creates a reserve that allows the preservation of cognition in spite of neuropathology.

A question currently of great scientific interest is how the investment in activities over the course of adulthood impacts cognitive health. There are two sorts of evidence that are germane to this issue. First, there is a solid experimental literature on *cognitive training* in which individuals are provided with instruction and practice in particular abilities or skills to improve mechanics (e.g., speed of processing, attentional control, reasoning, memory). The science on this question has been remarkably clear (Rebok et al., 2014; Stine-Morrow & Basak, 2011) in showing (a) the existence of plasticity into later adulthood with variability among individuals, (b) durability of training effects over significant periods of time, and (c) a large degree of specificity in the effects of training (i.e., limited transfer), such that improvement is typically restricted to only the exact skills trained and does not generalize even to ones that would be considered very similar to those trained. Another sort of evidence that is important to this question is the literature on the relationship between everyday activity engagement and cognition. Predominantly correlational and epidemiological, this body of work suggests that cognitive health may benefit from a lifestyle that is rich in mentally stimulating and social activities (Carlson et al., 2011; Rohwedder & Willis, 2010; Verghese et al., 2003). A number of such studies have included literacy engagement among other activities, but very few have examined its effects in isolation. However, there is some evidence that habitual literacy engagement in adulthood is related to delayed manifestation of late-life pathology (Kaup et al., 2013; Wilson et al., 2000). Of course, much of this evidence is vulnerable to interpretation in terms of reverse causation (i.e., cognitively healthy people might simply be more active). However, recent studies on lifestyle interventions (Carlson et al., 2008; Park et al., 2014; Stine-Morrow et al., 2014) have shown that it is possible to improve cognition through engagement in mentally stimulating activities (in the absence of explicit ability training). We discuss these correlational and intervention studies in the section “Reading, Literacy, and Language Processing.”

As the scientific community has tackled the question of late-life cognitive optimization with both creativity of approach and rigor, there is some public impatience for guidance about how to stave off cognitive decline and to protect against late-life pathology. This has contributed to a thriving industry of “brain training” involving computer-based practice in pattern recognition and attention to make us “sharper.” In spite of the very limited evidence for broad-based cognitive benefits of such products (Rabipour & Raz, 2012) and a questionable rationale given what is known from research in cognitive training, this has grown to a US$1.3 billion/year industry (Hambrick, 2014). This lag between the pace of scientific progress in discovering the principles of life span cognitive health and the development of business models of “neuroenhancement” will no doubt continue for some time, creating some confusion for consumers.

Largely neglected in this quest for life span cognitive health are educational approaches that engage literacy activities. In the paragraphs that follow, we consider why this might be a fruitful path to pursue.

Reading, Literacy, and Language Processing

A distinction can be drawn between reading and literacy (Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001). Reading is a mental activity in which engagement with print gives rise to an orchestration of cognitive (and neural) events that can evoke a wide array of phenomenological and emotional experiences, and contribute to knowledge acquisition. Although communicative competence in one’s native language can develop in minimal environments, the acquisition of skilled reading requires deliberate practice over an extended period of the life span, and a nontrivial proportion of individuals reach adulthood without acquiring this skill beyond a rudimentary level (NRC, 2012). Many aspects of reading rely on crystallized capacities (e.g., recognition and activation of meaning from words, use of syntactic structure, in varying degrees, cultural or domain-specific knowledge that enable inference), but even among skilled readers, mechanics plays an important role in comprehension. Literacy, however, is thought of as the collection of practices surrounding engagement with print and the cultural practices surrounding language. Thus, the development of skilled reading enables literacy engagement. In this section, we consider the interactive relationship among cognition, reading, and literacy. To preview, we argue that reading, and other forms of language processing, can be cognitively demanding activities that not only build crystallized knowledge, but have the potential to enhance cognition more broadly.

The Cognitive Demands of Reading and Language Processing

Reading is characterized by a complex cascade of operations that allow us to decode the surface form (i.e., the printed word or acoustic signal) into meaningful words to form syntactically licensed sentences, which ultimately fit into a broader discourse, or conceptual theme. As such, comprehension requires the generation of inferences to link the ideas from the text to those in the existing base of knowledge (McNamara & Magliano, 2009). Reading can engender thought and imagination, affording access to worlds that we may not be able to directly experience, so that it can be a highly active form of mental engagement (Gerrig & Jacovina, 2009; Mar & Oatley, 2008). For example, in reading for pleasure, individuals show measurable changes in facial muscle tension, galvanic skin response, and heart rate (Nell, 1988). Dynamic fluctuations in reading time show that readers do not only allocate attention to word and linguistic features but also to structural properties of narratives and expository texts and to the mental simulation of events (Bower & Morrow, 1990; Radvansky & Dijkstra, 2007; Stites, Luke, & Christianson, 2013; Zwaan, 1999).

It is well established that variation in cognitive abilities can affect language comprehension and memory for text. Because comprehension requires that language computations be conducted while storing products of ongoing processing, it can be demanding on mechanics, including working memory and executive control (Christianson, Williams, Zacks, & Ferreira, 2006; Daneman & Merikle, 1996; Fedorenko, Gibson, & Rohde, 2006; Novick, Trueswell, & Thompson-Schill, 2005; Swets, Desmet, Hambrick, & Ferreira, 2007).

Brain imaging during the course of reading and listening to stories shows that comprehension involves much more than the well-studied language areas (Fedorenko, Duncan, & Kanwisher, 2013), suggesting that reading may well be a "whole-brain" mental exercise. Indeed, comprehension engages many areas of the brain, including areas associated with perception, action, and emotion (Chow et al., 2014; Ferstl, Rinck, & van Crammon, 2005; Glenberg, Witt, & Metcalfe, 2013; Speer, Reynolds, Swallow, & Zacks, 2009; Xu, Kemeny, Park, Frattali, & Braun, 2005). Based on a meta-analysis of imaging studies examining the neural bases for the ability to infer the mental states of others ("theory of mind"), Mar (2011) concluded that the neural circuits that support narrative understanding overlap with those supporting theory of mind, including areas implicated in a range of cognitive processes (e.g., spatial navigation, autobiographical memory, mind-wandering). Research with event-related brain potentials suggests that the brains of effective readers continually attempt to predict input such that words violating these predictions generate larger negative electrical potentials at about 400 ms, called the N400 (Kutas & Federmeier, 2011). Also, lesion work (Barbey, Colom, & Grafman, 2014) suggests that discourse comprehension depends on widely distributed networks in the frontal parietal regions and the white matter tracts that connect them.

Given the nature of language processing as a highly active cognitive and neural activity, there is recently a growing interest in understanding whether literacy and language processing may impact cognition. Two sets of findings are relevant to this question: (a) the consequences of literacy engagement for language processing and "natural experiments" on the effects of illiteracy on mind and brain and (b) the benefits of lifelong bilingualism for attention and executive control abilities.

Effects of Literacy Engagement on Cognition

Systematic investigation of whether elective engagement in reading has a long-term impact on language processing and intellectual functions has been largely restricted to the study of children and college students. Reading experience is typically measured either by self-report of literacy activities or by checklists that assess recognition of unusual words (Barnes, Tager, Satariano, & Yaffe, 2004), or the names of authors, magazines, or periodicals (Mol & Bus, 2011). Measures based on self-reports and checklists tend to correlate with each other and with other measures of print exposure (e.g., number of books in the home, the ability to name a favorite author). Overall, these measures tend to show moderate correlations with language processing abilities (e.g., speed of decoding, verbal fluency, comprehension) even when fluid ability is controlled (Stanovich & Cunningham, 1992). Based largely on cross-sectional, correlational relationships, evidence for causal effects is thin. Nevertheless, there is some longitudinal work demonstrating lagged correlations with print exposure predicting language abilities and vice versa. In addition, there is evidence that the relationship between print exposure and language abilities increases through childhood, at least, to early adulthood. Such findings have prompted some to argue for a causal spiral between print exposure that contributes to more fluent reading, on one hand, and abilities that afford access to an ever wider range of texts, on the other (e.g., Mol & Bus, 2011).

The small body of work on the effects of print exposure in middle and late adulthood suggests that habitual literacy continues to impact language processing abilities. Print exposure can explain the increase in crystallized ability and knowledge through adulthood (Stanovich et al., 1995). Older readers with higher levels of print exposure process words more efficiently and allocate more attention to semantic processing, even when controlling for differences in vocabulary (Payne et al., 2012; Stine-Morrow, Miller, Gagne, & Hertzog, 2008). In addition, readers with higher levels of print exposure are more attuned to the statistical properties of syntactic structure (Payne et al., 2014). Finally, print exposure has been shown to modulate the well-replicated relationship between working memory (a fluid ability) and text memory, such that at the highest levels of print exposure, text recall is not at all constrained by poor working memory (Payne et al., 2012).

There are obvious everyday consequences of low literacy skills. Older adults with low health literacy—the ability to comprehend and make decisions about health information—often experience poorer health outcomes compared with proficient age- and health-matched individuals (Morrow et al., 2006; Sparks & Nussbaum, 2008). Financial literacy can impact employment, income, and retirement preparedness (Braunstein & Welch, 2002; Lusardi & Mitchell, 2007). Literacy has even been argued to be a keystone to promoting safety at home and in the workplace (Szudy & Arroyo, 1994). In other words, it is well recognized that literacy practices have the potential to increase crystallized verbal knowledge and domain-specific knowledge; the more startling possibility is that literacy may have the potential to impact attention, executive control, and other sorts of fluid abilities.

Perhaps the most striking evidence for the long-term effects of language use and literacy practices on mind and brain comes from natural experiments examining individuals who are deprived of literacy instruction for reasons unrelated to the ability to acquire literacy (Dehaene et al., 2010; Dellatolas et al., 2003; Huettig & Mishra, 2014; Ostrosky-Solis, 2004; Ostrosky-Solis, Ramirez, Lozano, Picasso, & Velez, 2004; Petersson, Ingvar, & Reis, 2009; Petersson, Reis, & Ingvar, 2001; Petersson, Silva, Castro-Caldas, Ingvar, & Reis, 2007; Wolf, 2007). This work suggests that literacy is associated with better short-term memory, especially for pseudowords lacking in meaning, suggesting that literacy enhances the development of the phonological short-term store, semantic fluency, episodic memory, phonemic fluency, visual recognition, and predictive processing in spoken language.

The effects of reading may also reach beyond language-related cognition. Consistent with the idea that narrative comprehension affords immersion into worlds with new places with new people, evoking the simulation of social experiences in particular (Gerrig & Jacovina, 2009; Mar & Oatley, 2008; Nell, 1988), adults higher in narrative print exposure score higher on objective measures of empathy (Mar, Oatley, & Peterson, 2009). There is weak evidence that literacy may impact functional connectivity. Fiber tracts that allow interhemispheric communication are thinner in the parietal area of illiterates. Berns et al. (2013) collected functional magnetic resonance imaging (fMRI) data on individuals to measure resting state connectivity before, during, and after they read a popular novel. A number of changes were identified, including increases in connectivity across left and right hemispheres, as well as a diffuse bilateral network with connections among areas related to language processing, sensorimotor control, and perception. These patterns alongside the mounting evidence detailed above are suggestive that there may be important effects of engaged reading on mental organization, which would prepare the mind to process subsequent experience and manage higher level cognitive tasks.

Effects of Lifelong Bilingualism on Cognition

Research on bilingualism reveals the interactive effects of language and cognition (Bialystok, Craik, Green, & Gollan, 2010). Relative to monolinguals, bilinguals have been found to have superior cognitive control ability to flexibly manage and switch between different thoughts and tasks, with some evidence that this is especially true for polyglots (Kavé, Eyal, Shorek, & Cohen-Mansfield, 2008). For example, in a study by Costa, Hernandez, and Sebastian-Galles (2008), participants were required to identify the direction of a central arrow when it was flanked by arrows that pointed to the same (congruous) or opposite (incongruous) direction. While both bilinguals and monolinguals were slower in the incongruous trials, the difference between congruous and incongruous trials was larger for monolinguals than bilinguals. Moreover, in Prior and MacWhinney (2010), participants were cued to focus on either the color or shape of a stimulus for each trial, and the attended feature might or might not switch between trials. Bilinguals showed smaller switching costs than monolinguals, as revealed by a smaller difference between switch and nonswitch trials. Together, these studies suggest that bilinguals have a more efficient executive control network to monitor and resolve conflict, and switch between tasks.

The "bilingual advantage" in attentional control has been attributed to the constant management of two language systems that is required by the bilingual mind. In fact, research indicates that bilinguals cannot switch off a language even in contexts where it is irrelevant (Dijkstra, 2005; Kroll, Bobb, & Wodniecka, 2006). For example, a Spanish–English bilingual touring Spain still has her English active all the time. Therefore, bilinguals need to constantly manage two sets of linguistic (e.g., phonological, syntactic) rules and items, which consequently enhances their cognitive control to speedily activate linguistic units relevant to the context while suppressing the irrelevant ones, and even allows them to switch between two linguistic systems more efficiently. This lifelong engagement with two languages could have neuroanatomical consequences. There is evidence that the brains of bilinguals are different from those of monolinguals, suggesting that experience with language can actually change how our brains develop and age. For example, results from voxel-based morphometry and diffusion tensor imaging show that bilinguals have higher gray matter density in left inferior parietal brain regions and higher white matter integrity in the corpus callosum. Resting-state functional connectivity analysis shows an increased anterior–posterior connectivity for bilinguals relative to monolinguals (Luk, Bialystok, Craik, & Grady, 2011; Mechelli et al., 2004). Better functional connectivity facilitates information transfer, which leads to improved executive control performance.

Age-comparative studies suggest that age-related declines in executive function are less extreme among bilinguals (Bialystok, Craik, Klein, & Viswanathan, 2004). There is also evidence that bilingualism may provide a buffer against late-life pathology. Based on a comparison of hospital records, Bialystok, Craik, and Freedman (2007) showed that bilinguals were diagnosed with dementia 3 to 4 years later than monolinguals. These effects are accompanied by neuroanatomical differences, such that relative to their monolingual counterparts, older bilinguals exhibit increased frontal lobe white matter that is directly related to their performance on a Stroop task, a canonical cognitive control task (Olsen et al., 2015). Interestingly, the amount of temporal gray matter also seems to be titrated to lifelong bilingualism, with aging monolinguals showing deteriorated gray volumes that are otherwise protected in bilinguals (Abutalebi et al., 2014; Olsen et al., 2015). Taken together, these cognitive and neuropsychological results underscore the importance of language experience over the life span as a potential contributor to preservation of executive control abilities.

Conclusion, Implications, and Recommendations

With the transition to an older population worldwide, there is increasing concern for pathways to cognitive resilience that enable individuals with longer life spans to function independently and to sustain satisfying lives. As a cornerstone of education, literacy engagement has long been recognized as a pathway to building knowledge. Neglected has been the possibility that language and literacy engagement may afford pathways to enhanced cognition more broadly, particularly in the realm of fluid abilities, which are the most vulnerable with aging. Research on the nature of reading shows that literacy activities rely on cognitive and neural mechanisms on a broad scale; research on the effects of literacy suggests that sustained engagement of these mechanisms may shape mental processes and their neural substrates over time. There are a number of implications.

The research that we have reviewed is both provocative and very incomplete, calling for a societal investment in science at the interface of education and health. Importantly, we have little understanding of the mechanisms through which literacy may promote cognitive health and longevity. Historically, the study of reading (as mental computations, neural processes, and their products) and the study of literacy practices and their effects have been largely independent. There is need for a literacy science that bridges this gap.

Concerns about the numbers of low-literacy adults (e.g., NRC, 2012) are heightened when considered in conjunction with the consequences of literacy for late-life cognition (e.g., Manly et al., 2004). Adult basic education programs are often not well equipped with effective instructional tools or resources to meet the needs for adult literacy learners. To complicate the matter, those who are the weakest in skill level are also the least likely to seek out adult education and training (OECD, 2013). This is a good example of the developmental Principle of Corresponsiveness (Caspi, Roberts, & Shiner, 2005), which suggests that we seek out environments that are most consistent with our predispositions, which thereby reinforce those characteristics. In the case of low literacy, we must develop ways to disrupt corresponsiveness, creating inviting avenues to adult education. In part, this will require some understanding of the stigma associated with illiteracy and other barriers to accessing adult education.

Finally, we must innovate to develop new models of life span education. Some time ago, Riley and Riley (2000) noted the tendency in Western culture for age segregation in which available societal roles are tightly tied to age. Importantly, education has been expected of and available to the young. Education, which promotes the continued development of literacy, at whatever level, must be a life span endeavor.

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