A novel theoretical life course framework for triggering cognitive development across the lifespan

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Abstract

Although intellectual engagement is a significant factor associated with adult cognitive health, it is unclear what it includes, why and how it declines across the lifespan, and importantly, whether its decline has a causal role in cognitive aging. This integrative review introduces a novel theoretical life course framework that synthesizes research on early childhood experiences and cognitive aging to address the following three points. First, we specify six critical factors of "intellectual engagement" for long-term, broad cognitive development: 1) open-minded input-driven learning, 2) individualized scaffolding, 3) growth mindset, 4) forgiving environment, 5) serious commitment to learning, and 6) learning multiple skills simultaneously. We show that these factors increase basic cognitive abilities (e.g., working memory, inhibition) and promote far transfer. Second, we trace the decline of the six factors from infancy to aging adulthood (broad learning to specialization). Finally, we propose that these six factors can be applied to expand cognitive functioning in aging adults beyond currently known limits.

A novel theoretical life course framework for triggering cognitive development across the lifespan

What factors cause age-related cognitive decline in many healthy older adults? Some studies applying a full lifespan approach have focused on tracking early life factors that impact later aging (e.g., education; Sharp & Gatz, 2011), or identifying early biomarkers (e.g., Belsky et al., 2015). Most studies have investigated this question via research from younger to older adulthood. These studies have identified several candidate factors, including neural degeneration (e.g., Grady, 2012; Raz & Rodrigue, 2006), lack of social and environmental support (e.g., social networks, technology use; Ackerman, Kanfer, & Calderwood, 2010; Stine-Morrow, Parisi, Morrow, & Park, 2008), reduced physical activity (e.g., Erickson et al., 2011), and reduced engagement in intellectually stimulating activities (Hultsch, Hertzog, Small, & Dixon, 1999; Ihle et al., 2015; Parisi, Rieger, & Carlson, 2014; Scarmeas, Levy, Tang, Manly, & Stern, 2001; Voss, Carr, Clark, & Weng, 2014). Although many candidate factors may interact to cause age-related decline, this review focuses on intellectual engagement because interventions that aim to change levels of intellectual engagement can be scalable, holistic, non-invasive, individually adaptive, generalizable to useful real world abilities, and unlikely to have harmful side effects. Moreover, prior engagement interventions with aging adults have been relatively successful in terms of high retention rates (e.g., Carlson et al., 2009), efficacy (e.g., Noice, Noice, & Kramer, 2014), and transfer to untrained skills (i.e., broad transfer; Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007; Noice et al., 2014; Park et al., 2014; Stine-Morrow et al., 2008). Finally, changes in intellectual engagement may have cascading effects (i.e., a chain reaction due to an initial change in a system) on other factors, such as neural plasticity (e.g., Lövdén, Bäckman, Lindenberger, Schaefer, & Schmiedek, 2010; Merzenich, 2013; Park & Reuter-Lorenz, 2009) and quality of life (e.g., Noice et al., 2014). For example, an aging adult could be shown that they are capable of learning new skills, feel more empowered, and then continue to seek challenging opportunities that they otherwise would avoid.

Based on prior research on intellectual engagement in aging adulthood, it is unclear what the key factors of intellectual engagement are, why and how it declines across the lifespan, and importantly, whether its decline has a causal role in cognitive aging. First, prior studies on intellectual engagement include a wide range of activities, from high to low challenging situations (e.g., a cognitively demanding job, photography lessons, social gatherings, book clubs, and leisure activities; Gajewski et al., 2010; Ihle et al., 2015; Park et al., 2014; Stine-Morrow et al., 2008). Therefore, it is unclear what key factors are required for an activity to be considered "engaging." Second, aging studies typically explain the decline of intellectual engagement based on late-life milestones, such as retirement (e.g., Rohwedder & Willis, 2010). Although there is a pronounced decrease in intellectually engaging activities for many older adults from pre- to post-retirement, we argue that these activities actually decrease throughout the lifespan, not just during older adulthood. Finally, many observational studies report positive correlations between intellectual engagement and the maintenance of cognitive abilities in older age (Hultsch et al., 1999; Wilson, Scherr, Schneider, Tang, & Bennett, 2007). However, other studies have observed small or no associations (e.g., Salthouse, Berish, & Miles, 2002), and experiments testing the causal link report inconclusive results (e.g., Salthouse, 2006) or perhaps only short-term (though broad) gains (e.g., Bugos et al., 2007; Noice et al., 2014; Park et al., 2014; Stine-Morrow et al., 2008).

Building on this literature, this integrative review introduces our novel theoretical framework, CALLA (Cognitive Agility across the Lifespan via Learning and Attention), which adopts a full lifespan approach (i.e., from infancy to aging adulthood). Our novel framework originates from our collaborative efforts in reviewing critical factors contributing to cognitive development during childhood and factors contributing to cognitive decline during aging adulthood, as well as factors that seem to produce favorable effects in cognitive aging interventions. CALLA has three major arguments: 1) we specify six critical factors of intellectual engagement, 2) explain why and how these factors decline across the lifespan, and 3) provide initial evidence that engagement of these factors produces beneficial results and specific predictions to test their causal role in cognitive development in aging adults. The centrality of these six factors in our framework is based on their prevalence during infancy and childhood, their decline from young adulthood to older adulthood, the problems faced by older adults, and hints of their beneficial effects in cognitive interventions with aging adults. In presenting the six factors of intellectual engagement, we show that they increase basic cognitive abilities (e.g., working memory, inhibition) and promote far transfer (i.e., generalization to untrained skills; Barnett & Ceci, 2002) (Section A). In tracing the decline of these factors from infancy to aging adulthood, we argue that the adaptive transition from largely broad learning to specialization may trigger the onset of healthy cognitive aging (Section B). We propose that these six factors can be applied to improve cognitive functioning in aging adults beyond currently known limits

(Section C). Finally, we discuss other theoretical considerations of our framework and conclusions (Sections D & E).

A. Six critical factors of intellectual engagement for broad learning

If the goal of engagement interventions with healthy aging adults is to induce long-term, broad cognitive development (i.e., sustained increase in cognitive abilities in a wide variety of contexts), then research on broad learning (i.e., acquisition of information and skills across a variety of contexts) during early childhood should be extremely informative for aging research and interventions. Early childhood experiences offer “intellectual engagement” in the form of broad learning over multiple years across the lifespan, which results in broad cognitive development in healthy infants and children. Here, we present six factors that can be adapted from broad learning during childhood to aging interventions (but are often overlooked in aging research): 1) open-minded input-driven learning, 2) individualized scaffolding, 3) growth mindset, 4) forgiving environment, 5) serious commitment to learning, and 6) learning multiple skills simultaneously. We have included these six factors in our framework because they are present from infancy and critical for child development, but decline from young adulthood to older adulthood. Moreover, there is initial evidence that some of these factors may lead to beneficial effects in aging adults.

In this section, we explain each of these factors, and briefly review research demonstrating that these factors increase basic cognitive abilities (e.g., working memory, inhibition, cognitive control) and promote far transfer, the “holy grail” of aging interventions. Section B highlights their decline from childhood to older adulthood.

A.1. Explanation of six critical factors for broad learning

1. *Open-minded input-driven learning:* Open-minded input-driven learning involves observing and using patterns in the environment (Saffran, Aslin, & Newport, 1996; Wu, Gopnik, Richardson, & Kirkham, 2011) more often than relying on prior knowledge gained from previous experiences. This concept differs from closed-minded knowledge-driven learning, where the learner relies more on prior knowledge (e.g., schemas, routines, assumptions) than input to acquire information for a given task. The difference between input-driven and knowledge-driven learning can be exemplified by learning language in two different ways: 1) starting with a prolonged period of listening and babbling to precisely learn the sounds and common phrases of a language versus 2) starting with fast-mapping of vocabulary words from a known language to new language. The first strategy is often used by infants and children learning a first or second language, while the second strategy is often used by adults learning a second language. Although both knowledge and input are required for learning (e.g., new information can build on previous knowledge), we argue that cognitive development requires a greater reliance on input (and newly-acquired knowledge based on this input) rather than entrenched knowledge (i.e., knowledge from familiar routines and schemas). Input-driven learning is most apparent when knowledge increases in a novel domain (e.g., learning to sing when the learner already knows how to play the piano), rather than a familiar domain (e.g., learning a new piano piece as an expert piano player). Input-driven learning is most easily elicited in completely novel situations (i.e., where there is the greatest mismatch between environmental demand and prior knowledge; Lövdén et al.,

2010), such as traveling or even moving to a new country with a very different culture or learning a completely new skill. Inevitably, this factor leads to greater exploration and novel experiences, which is beneficial for cognitive development, and possibly older adults. Input-driven learning typically requires longer time-frames to achieve proficiency, although it ultimately promotes better adaptation to novel situations relative to knowledge-driven learning (e.g., language learning, Kuhl, Tsao, & Liu, 2003). When fully adapted, input-driven learners outperform knowledge-driven learners in many situations (e.g., the difference between native and non-native speakers). Beyond productivity (Festini, McDonough, & Park, 2016; Friedman & Martin, 2011), which may involve familiar routines, open-minded input-driven learning encourages learners to acquire novel information and use existing knowledge in novel ways. As a result, the learner receives practice in a novel situation using fluid intelligence (e.g., Stine-Morrow et al., 2008) and other basic cognitive abilities (e.g., cognitive control, episodic memory; Bugos et al., 2007; Noice et al., 2014; Park et al., 2014) to achieve appropriate responses, and in distinguishing relevant from irrelevant information (e.g., Wu et al., 2013). Variety in the types of novel tasks likely would allow for exposure to different ways of challenging basic cognitive abilities (Carlson et al., 2012). Finally, this concept is related to openness to experience as a personality trait (e.g., Sharp, Reynolds, Pedersen, & Gatz, 2010; Stine-Morrow et al., 2014) and the Need for Cognition construct (e.g., Fleischhauer et al., 2010), but focuses on a specific learning approach rather than a general personality trait.

2. *Individualized scaffolding:* This factor refers to incrementally increasing the difficulty of the to-be-learned items based on the learner's abilities (e.g., Obradović, Yousafzai, Finch, & Rasheed, 2016; Vygotsky, 1978). Developmental psychology has accepted for decades that scaffolding is a critical factor promoting cognitive development, especially when children are faced with a situation that is beyond their current abilities (e.g., Wu et al., 2011). The goal of scaffolding is to provide initial support for the learner so that eventually the leaner can perform the task on her own. Scaffolding, along with feedback, in the natural environment often comes from caregivers and teachers (Vygotsky, 1978), who can provide a constrained environment with tolerable input (e.g., restricted vocabulary in infant-directed speech). Caregivers and teachers can highlight the subset of relevant information to learn among distraction, and gradually lead the learner to the appropriate responses. The learner also can reduce input: for example, infants are extremely near-sighted at birth, which can highlight some items to learn (e.g., the caregiver's face) and reduce a lot of the clutter from the natural environment. However, scaffolding from caregivers and teachers provides the suitable expertise to distinguish relevant from irrelevant learning events, which may not always be salient or apparent. More recent research has demonstrated how and when infants and children learn from people (e.g., Koenig & Sabbagh, 2013), as well as characterizing the nature of "scaffolding" and its effects in finer detail (Harris & Almutairi, 2016; Van De Pol, Volman, & Beishuizen, 2010). For disadvantaged children, a scaffolding intervention with the primary caregiver increases basic cognitive skills, as well as academic abilities (Obradović et al., 2016). For adults, learning can often be self-paced or computerized, which

may lead to some gains (e.g., Dunlosky et al., 2007; Mishra, de Villers-Sidani, Merzenich, & Gazzaley, 2014).

3. *Growth mindset:* Growth mindset (e.g., Dweck, 2006) refers to the belief that abilities are not fixed, but rather can develop with enough effort and dedication from the learner (e.g., talent/intelligence is not innate). Growth mindset contrasts the fixed mindset, where the learner (or teacher) believes that abilities are based on innate properties that cannot be developed (e.g., "This child is smart, and that child has the artistic gene."). A growing literature demonstrates that learners with a growth mindset are more willing to tackle difficult problems, are more willing to make mistakes, have more confidence, achieve more, and persevere despite setbacks (e.g., Dweck, 2006; Jaeggi, Buschkuehl, Shah, & Jonides, 2014; Yeager & Dweck, 2012). A number of interventions with children, adolescents, and teachers also demonstrate that a fixed mindset can be changed to a growth mindset, with ensuing benefits (e.g., Yeager & Dweck, 2012). One could argue that any learner or instructor imposing a permanent or declining upper bound on abilities is engaging the fixed mindset. The lack of infant and aging adult studies on growth or fixed mindsets suggests that this problem is not present or meaningful with either age group, but is heightened during adolescence and young adulthood. However, this gap in the literature speaks volumes to the issue at hand: Perhaps the accepted standard for healthy infants is growth (i.e., engaging the growth mindset), and decline for aging adults (i.e., engaging the fixed mindset), although research on aging interventions aim to counteract this accepted standard.

4. *Forgiving environment:* This factor refers to a supportive learning environment that allows the learner to make mistakes and reduces the pressure of immediately producing good results. In addition, it also refers to an encouraging environment and culture that minimizes negative stereotypes and low expectations, especially ones related to not being able to learn (Rosenthal, 1994). In relation to research on growth mindset, Dweck (2006) refers to this type of environment as promoting the term "not yet" rather than finite phrases, such as "cannot." Open-minded input-driven learning requires a forgiving environment to provide the learner with ample time to observe patterns and make (correct or incorrect) inferences. Moreover, the learner may be able to learn a task faster if she can learn from her mistakes (Herzfeld, Vaswani, Marko, & Shadmehr, 2014). The concept of a forgiving environment extends beyond a "helpful" environment, as seen in "aging in place", where an assisted living facility or care team in the older adults' home adjusts its program of care to fit the aging adult's requirements. Although this concept may resemble aspects of the scaffolding factor, situations involving "aging in place" typically include ageism, promote cognitive *maintenance* rather than *development*, favor routines, and rely on older adults' existing knowledge (rather than encouraging them to learn new skills). This concept of "aging in place" does not exist in child development, because growth likely would not occur under these constraints.

5. *Serious commitment to learning:* This factor refers to learning new skills and acquiring new information for survival (e.g., infants learning to talk and walk), rather than "hobby learning," where the learner casually picks up skills for a short period and then quits due to

difficulty, disinterest, or other time commitments. For older adults, this factor may be loosely related to a sense of purpose (e.g., Boyle et al., 2012). In cognitive development, neuroscience, and robotics research, a serious commitment to learning is often inherent in concepts such as curiosity or intrinsic motivation, where learning and information are themselves reinforcing (Oudeyer & Smith, 2016). In the learner, this factor is also related to notions of perseverance or "grit," which has been shown to be predictive of high personal and academic achievements (Duckworth & Gross, 2014). This factor may initially be implemented by the instructor if the learner does not display a serious commitment to learning.

6. Learning multiple skills simultaneously: This factor is at the core of broad learning (i.e., learning many different skills) and may lead to broad transfer (increased abilities in untrained skills). This factor can be exemplified by infant development (e.g., simultaneous visual, auditory, motor, social, and tactile development), as well as enrolling in different core classes throughout formal schooling. Learning many different skills at the same time may encourage far transfer (Simons et al., 2016), which can be defined as applying a set of skills acquired from one domain to another domain where there are underlying parallels (Barnett & Ceci, 2002). Links can be drawn among simultaneously active domains and skills (e.g., a key factor in creativity; Lindell, 2014), and broadly improve basic cognitive abilities, such as cognitive control (Abrahamse, Braem, Notebaert, & Verguts, 2016). However, this factor may require an extended period before cognitive benefits are observed compared to learning only one skill at a time (Park et al., 2014).

These six factors are distinct, but overlap and interact in interesting ways. Four of these factors pertain more to the learner (open-minded learning, growth mindset, serious commitment, learning multiple skills), while the other two pertain more to the learning environment (scaffolding, forgiving environment). Learner and environmental factors likely interact during adulthood, as they do during childhood. For example, scaffolding from an instructor could promote open-minded input-driven learning and a growth mindset, which could also lead adult learners to find instructors who scaffold more. Instructors who scaffold can help learners maintain a serious commitment to learning, especially if the learner has a low commitment to learning. Instructors and learners with a growth mindset could have a serious commitment to open-minded learning, and promote or seek a forgiving environment. People with a serious commitment to learning may also seek simultaneous learning opportunities.

These factors may allow us to open new learning opportunities to increase the likelihood of cognitive development across the lifespan. We believe these factors can shift older adults' lifestyle approach to "trigger" cognitive development, but these factors are often overlooked in aging interventions. The concept of "triggers" and "brakes" originates from the critical period literature (e.g., Werker & Hensch, 2015). This literature is moving beyond demonstrating the presence of critical periods (i.e., a period of maximal sensitivity to acquire a skill beyond which it may be impossible), and instead focusing on the factors (i.e., “triggers” and “brakes”) that open, sustain, and close these periods. We argue that the six proposed factors (and possibly others) are among the most important for "triggering" adult cognitive development. This argument is based on the decline of the factors from childhood to aging adulthood and the problems faced during aging adulthood (reviewed in Section B), as well as promising cognitive interventions with aging adults (reviewed in Section C).

B. Decline of the six factors from childhood to aging adulthood

In this section, we review the decline of these six factors across the lifespan and provide an explanation for the decline. Baltes' theory on lifespan development (Baltes, Lindenburger, & Staudinger, 2006) is one of the few influential theories of aging to consider the entire lifespan, and lays the groundwork for the arguments of our framework (CALLA). According to Baltes' theory, and echoed by Schaie and Willis (2000), childhood is a period of growth, young adulthood is a period of maintenance, and aging adulthood is a period of loss regulation via compensation, where losses exceed gains. During infancy and childhood, it is adaptive to develop life skills in a variety of contexts (i.e., broad learning), and gradually specialize (Gopnik, Griffiths, & Lucas, 2015; Thompson-Schill, Ramscar, & Chrysikou, 2009). During young adulthood, it is adaptive to build on these acquired skills and specialize even more to be efficient and highly trained in a smaller number of areas, typically in one area of expertise. Throughout middle-age and older adulthood, it is adaptive to specialize even more to maintain declining cognitive abilities (Baltes et al., 2006).

We argue that in following the adaptive progression from broad learning to specialization throughout the lifespan, there is a decrease in the six factors because specialization favors short-term efficiency, while the six factors favor long-term adaptation for broad learning (Figure 1). While specialization, especially to expertise, requires years of training, the aim of specialization is to efficiently use existing knowledge in a familiar environment, whereas broad learning prioritizes full adaptation to novel environments. The next three sections trace the prevalence and decline of the six factors from infancy to aging adulthood.

B.1.1. Prevalence and importance of the six factors during infancy and childhood

The presence of the six factors is especially obvious during infancy. Compared to adults, young infants have very limited knowledge and are therefore highly input-driven ("infants are like sponges"). Over the first year of life, infants observe patterns in the environment to acquire knowledge (i.e., open-minded input-driven learning, Factor #1; Saffran et al., 1996; Wu et al., 2011), such as tracking features that belong to particular objects (Wu et al., 2011) and learning sounds for a particular language (e.g., Kuhl et al., 2003). As they gain knowledge, infants can also test "hypotheses" to guide their knowledge acquisition process, while observing the outcome to adjust their hypotheses accordingly (i.e., the child as a scientist, Gopnik, 1996). To help infants learn about relevant items, caregivers in the natural environment typically accommodate infants' cognitive limitations by restricting the items presented to the infant, such as displaying only a small number of relevant toys. By incrementally increasing the difficulty of the to-be-learned items based on the learner's abilities (i.e., scaffolding, Factor #2; Vygotsky, 1978), caregivers dramatically increase the likelihood of an infant learning about a particular event. Interestingly, in some situations, infants are also capable of choosing to focus on and learn from events that have a tolerable amount of uncertainty (e.g., Kidd, Piantadosi, & Aslin, 2012). Infants are immersed in forgiving environments (Factor #3) with plenty of time to make mistakes while learning essential skills. For example, for the first 8 months or so of life, infants listen and babble (while receiving feedback) to hone their ability to recognize and produce the appropriate sounds of their native language. Mistakes (e.g., inappropriate pronunciations while learning how to speak, falling down while learning how to walk) are accepted and sometimes corrected, as caregivers slowly guide the infant to produce the appropriate behaviors. From this forgiving environment, young learners can develop a growth mindset, the belief that abilities are not fixed, but rather can develop with enough effort and dedication from the learner (Factor #4; e.g., Dweck, 2006). Moreover, infants and caregivers are typically committed to learning either via intrinsic motivation or external pressure (Factor #5), as the stakes are extremely high if these survival skills (e.g., learning to speak, walk, read) are not mastered. Finally, infants are required to learn many skills within a short amount of time (Factor #6), and skills from one domain can bolster those from another. For example, the ability to sit upright allows infants to pick up objects and learn about three-dimensionality (e.g., Soska, Adolph, & Johnson, 2010). These six factors interact to allow the young learner to be highly adaptable to novel situations. Even cases of specialization in young children (e.g., prodigies) still promote the six factors to transform gifted children into successful adults, rather than under-achieving adults (Winner, 1997). During childhood, in stark contrast to aging adulthood, cognitive performance increases dramatically across multiple domains. Besides genetic/epigenetic factors, the six aforementioned factors contribute significantly to cognitive development early in the lifespan.

B.1.2. The start of the decline of the six factors during young adulthood and middle-age

Younger and middle-aged adults often outperform other age groups on a variety of measures, can use knowledge very efficiently, and are highly experienced in acquiring new information. During this general peak and plateau of the lifespan, however, the costs of knowledge-driven behaviors become more apparent and frequent as learners prioritize relevant or necessary events as defined by previous experience (decrease in open-minded learning, Factor #1). Classic examples include not seeing or hearing events that are unexpected, such as change blindness, as well as preferring familiar over novel, such as false memories, the cocktail party effect, and confirmation bias. In general, when experimental contexts violate statistics from the natural environment (e.g., using non-predictive rather than predictive stimuli), adults may use inappropriate cognitive models and heuristics to solve the task (i.e., inappropriate for the specific experiment but appropriate for the natural environment; Blanco et al., 2016; Orhan, Sims, Jacobs, & Knill, 2014). To be clear, children also exhibit errors based on acquired biases in familiar contexts. One example is when children overgeneralize rules prior to learning irregular past tense forms (e.g., we "goed"). Biases also constrain future learning (e.g., reduced exploration for known object functions in children; Bonawitz et al., 2011). However, infants and children still exhibit high levels of open-minded, input-driven learning to recover from errors made from inaccurate assumptions and inferences.

For many individuals, young adulthood (after the highest degree achieved) also marks the end of broad learning and continuous exposure to the six factors due to amplified specialization. In fact, some even propose that the child development process is an efficient solution found by natural selection for the better adaptation of humans to a familiar environment (Gopnik et al., 2015). By this period, adults acquire jobs and build families that often exploit existing skills in specific areas (e.g., Labouvie-Vief, 1980). The timing of such specialization varies within and between societies (Arnett, 2000). But in all cases, few young adults start jobs that require additional long-term broad training (e.g., Ph.D. students), which utilize many cognitive development factors such as a mentor who scaffolds the learner's abilities. Even these unique cases typically aim to specialize learners within a few years (e.g., becoming an expert in a specific research area) to be productive enough and reach enough depth to make a significant contribution. For many young adults, largely due to societal demands and individual circumstances, the rate of acquiring new knowledge in a variety of domains largely decreases to allow for selective focus on and exploitation of particular domains (e.g., selective optimization, Baltes et al., 2006; decreased information seeking, Carstensen, 1995). In other words, it becomes adaptive in the short-term for the young adult to specialize.

B.1.3. The steep decline of the six factors during older adulthood

Age-related decline from middle-aged to older adulthood affects numerous cognitive abilities. Except for a few domains, such as knowledge and vocabulary, most cognitive abilities decline for many adults (Hartshorne & Germine, 2015; Park & Reuter-Lorenz, 2009). A number of neurobiological factors have been linked with cognitive aging include shrinking dendritic fields, shrinking brain volume, declining coherence in neural activity, and declining effectiveness of neurotransmitter systems, which lead to overall decreased likelihood of inducing neuroplasticity (Grady, 2012; Raz & Rodrigue, 2006). In addition to these neurobiological factors, many studies have identified other factors linked to cognitive decline that relate to the aforementioned six cognitive development factors, including lack of intellectual engagement (e.g., early retirement from a cognitively demanding job; Rohwedder & Willis, 2010), favoring short-term efficiency (e.g., routines; Tournier, Mathey, & Postal, 2012; Zisberg, Zysberg, Young, & Schepp, 2009), perceived social isolation (e.g., Cacioppo & Hawkley, 2009), and negative stereotypes/self-perception (e.g., Levy et al., 2015; Robertson, King-Kallimanis, & Kenny, 2015).

An extreme example of exhibiting low levels of open-minded input-driven learning is that older adults tend to favor routines over changes to routines (Bouisson & Swendsen, 2003). For older adults, increased routinization (i.e., extreme adaptation to specific environments) is associated with decreased levels of working memory, speed of processing, and attention (Tournier et al., 2012), and other measures of well-being (Zisberg et al., 2009). In addition, repetitive jobs may lead to faster cognitive decline, relative to more cognitively variable jobs (Gajewski et al., 2010). Routinizing and automatizing is advantageous in the short-term because it is less taxing, more efficient, and produces fewer errors relative to more deliberate processing. In addition, automatizing leads to similar performance between younger and older adults in familiar situations (e.g., Rawson & Touron, 2015). For aging adults experiencing cognitive decline, it is advantageous in the short term to favor routines to maintain a certain level of functioning. Favoring routines in older adulthood may mirror a similar phenomenon in childhood, as children are inundated with new experiences and new events to learn. For infants and children, however, caregivers may build and amend (or even break) their children's routines to scaffold their ability to learn from new experiences, rather than allowing them to remain comfortable in their routines. Continuing to engage in stimulating activities related to one's expertise (e.g., chess) may allow adults to maintain general cognitive abilities for a longer period of time compared to novices (Vaci & Gula, 2015). However, specializing ultimately reduces adaptation to novel situations due to increased constraints imposed by prior knowledge, perhaps leading to cognitive decline apparent in novel and eventually familiar situations.

Another example of favoring knowledge-driven approaches rather than input-driven approaches is the decreased ability (relative to young adults) to ignore previously relevant information, such as previous targets in a visual search task (e.g., Madden, 1983), while the ability to use previously or newly relevant information is retained (e.g., predictable target side, Carlson, Hasher, Connelly, & Zacks, 1995; realistic shopping prices, Castel, 2005). Older adults can even retain information from distractors that may seem relevant (e.g., Campbell, Healey, & Lee, 2012) and use this information when distractors become targets (see Amer, Campbell, & Hasher, 2016). In other words, familiarity with targets and distractors may result in a weak distinction between relevant and irrelevant items in a particular task. This result mirrors a similar weak distinction in infants and young children, although in latter case, it is based on too little knowledge of what is relevant (e.g., Wu et al., 2011). When targets are consistently relevant or irrelevant throughout an entire task, older adults (as well as younger adults) have improved performance (Chiu & Egner, 2016; Hertzog, Cooper, & Fisk, 1996). Issues with switching between or "reweighting" relevant and irrelevant items may be related to a reluctance in older adults to switch in general because it induces switch costs (e.g., Mayr, 2001). Therefore, apparent cognitive problems in aging adults, such as a reduced ability to ignore irrelevant information, may sometimes result from a problem in identifying previously relevant information as irrelevant for a current task, which may be an underlying factor driving an increase in general distractibility in older adults. Increased knowledge in general also may induce retrieval issues that resemble "memory decline" for similar reasons (Ramscar, Hendrix, Shaoul, Milin, & Baayen, 2014). For older adults, besides neurodegeneration factors, reduced cognitive abilities, especially in novel situations, may be due to using familiar, inappropriate cognitive models and heuristics, also seen in young adults (e.g., Orhan et al., 2014). Perhaps consistently using outdated or inappropriate cognitive models in novel contexts may be a marker of specialization and even cognitive aging, especially when responses become slower and less accurate as a result.

Decision making research has shown that while older adults can learn new information, when compared to younger adults, older adults have difficulty learning and using new decision tree models that incorporate new data that would help them adapt to various situations (Worthy & Maddox, 2012). Moreover, new models developed by aging adults tend to be situation-specific and based on less information than the more elaborate models generated by younger adults in novel situations (e.g., Worthy & Maddox, 2012). Exploration also seems to decrease with age (e.g., Mata et al., 2013), which may lead to decreased learning from novel input. Aging adults do use environmental input (e.g., reminders for upcoming tasks; Lindenberger & Mayr, 2014), but perhaps more to confirm existing knowledge, rather than exploring novel contexts. Janacsek et al. (2012) hypothesize that decreased implicit statistical learning abilities (input-driven learning in CALLA), in addition to increasingly solidified internal cognitive models (knowledge-driven learning in CALLA), is a significant factor contributing to decreased behavioral performance in older adults. However, aging adults are able to engage in statistical learning (e.g., Campbell et al., 2012), though aspects may be qualitatively different from infants and children (Schwab et al., 2016).

Finally, there is a great deal of research on the prevalence of ageism, negative stereotypes, negative self-perception, and limited time perception (e.g., Kite, Stockdale, Whitley, & Johnson, 2005; Levy et al., 2015; Nelson, 2005). These studies suggest that there is an unforgiving environment with no scaffolding that does not encourage aging adults to acquire new knowledge or make mistakes while learning. Moreover, the lack of growth mindset research with aging adults suggests that it is not considered important in this age group, perhaps due to negative stereotypes held by researchers on aging. To our knowledge, there is also currently no research investigating the learning commitment level of older adults and likelihood of learning multiple skills simultaneously. However, given the prevalence of research highlighting ageism (e.g., Kite et al., 2005), age-based stereotype threat (e.g., Lamont, Swift, & Abrams, 2015), and routinization (e.g., Tournier et al., 2012; Zisberg et al., 2009), as well as an emphasis on cognitive maintenance rather than cognitive development, it is highly likely that these factors are reduced in aging adulthood relative to infancy and childhood. Even questionnaires on active lifestyles in aging adults (e.g., Hultsch et al., 1999) focus on hobbies, which differ from intense meaningful learning of survival skills during infancy and childhood.

B.1.4. Conclusions

In sum, throughout the lifespan, the learner trades off between broad learning and specialization based on existing resources and constraints. Broad learning is characterized by slow adaptation to a variety of contexts largely based on environmental input, while specialization is characterized by efficient use of acquired knowledge and skills. This tradeoff is related to the stability vs. plasticity trade-off from neural development (e.g., Werker & Hensch, 2015). While using both sources of information can be beneficial, some tasks require more input and less prior knowledge when adapting to different situations and more knowledge and less input when producing results. Early childhood experiences tend to favor broad learning over specialization (Gopnik et al., 2015; Thompson-Schill et al., 2009). Although there is some specialization during these early periods (e.g., perceptual narrowing), young learners remain receptive to novel information via the six factors for an extended period to acquire a variety of life skills (e.g., walking, learning the native language(s), learning about caregivers and other social partners, learning a variety of subjects in school). By contrast, from young adulthood onwards, specialization (i.e., increased use of previously acquired knowledge, decreased need for broad knowledge acquisition; Baltes et al., 2006; Schaie & Willis, 2000) becomes the more adaptive strategy, and this shifted balance remains and intensifies throughout aging adulthood.

We propose that this adaptation may induce brakes in cognitive development and triggers for cognitive aging. Extended periods of specialization in familiar contexts (ranging from "focusing" to "entrenchment") with little broad learning may lead to reduced adaptation to novel environments and to increased automatization in familiar environments. We hypothesize that a prolonged period of favoring short-term efficiency for specialization over long-term adaptation is a significant cause of cognitive aging due to restricted practice in acquiring novel information and using existing knowledge in new ways (c.f., Stine-Morrow et al., 2014). The reviewed studies suggest that the optimal strategy for adults is to balance the two approaches to allow for efficiency in familiar contexts, while being open to learning new information in novel contexts – harnessing the benefits from input- and knowledge-driven learning, while avoiding the costs of both.

C. Improving cognitive function in aging adults via broad learning

We propose that the six aforementioned factors remain important throughout the lifespan, not just during childhood, and that they can be applied to expand cognitive performance in aging adults beyond known limits. In this section, we first briefly review prior interventions in relation to the six factors to provide a unifying approach for understanding successful and unsuccessful training outcomes. Second, we provide suggestions for incorporating the six factors into future interventions.

There is mounting evidence that altering learner and environmental factors in older adults can increase cognitive functioning (see Hertzog, Kramer, Wilson, & Lindenberger, 2009), and induce some neuroplasticity (e.g., Draganski et al., 2004; Merzenich, 2013). Hertzog et al. (2009) highlight four criteria that cognitive interventions for healthy aging adults should fulfill: 1) transfer to untrained domains, 2) maintain training effects over time, 3) increase everyday life skills, and 4) apply to a heterogeneous population of older adults. Current tactics for enhancing cognitive functioning in older adults include physical activity and exercise (e.g., Erickson et al., 2011), general intellectual stimulation (e.g., photography, quilting, problem solving; Park et al., 2014; Stine-Morrow et al., 2008), environmental support (e.g., social networks, tech-driven advances; Ackerman et al., 2010; Carlson et al., 2009; Stine-Morrow et al., 2008), and training specific cognitive abilities, such as working memory, speed of processing, and reasoning (e.g., Anguera et al., 2013; Ball et al., 2002; Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; see Kueider, Parisi, Gross, & Rebok, 2012 for a review). These interventions range from training single to multiple factors to total immersion in new environments.

Some of the most successful interventions to date have utilized variations of some (but not all) of the six cognitive development factors from CALLA, including open-minded input-driven learning (e.g., Bugos et al., 2007; Noice et al., 2014; Park et al., 2014; Stine-Morrow et al., 2008), individualized scaffolding (e.g., Mishra et al., 2014), and commitment to the intervention (e.g., Carlson et al., 2009). These studies have typically demonstrated some near and far transfer effects, as well as some effects lasting between a few months (e.g., Bugos et al., 2007) to even a decade (Rebok et al., 2014). Some attribute the cognitive gains from these interventions to the integration of multiple networks (Bugos et al., 2007) or sustained engagement and mental stimulation resulting in a boost in frontal lobe functioning (e.g., Carlson et al., 2009; Park et al., 2014). We propose that the presence of some of the six factors in the prior interventions triggered cognitive development processes, including subsequent neurobiological and behavioral effects. We also argue that interventions that omit many of the six factors may limit the amount and type of cognitive gains experienced by the aging adult participants. Despite some success in cognitive intervention research with aging adults, a number of comprehensive reviews and meta-analyses reveal issues with many cognitive intervention studies. Many training programs have issues with improving skills beyond the specifically trained skill, sustaining training outcomes for more than a few weeks, or the lack of a deep understanding of the cognitive mechanisms and processes driving the change (e.g., Simons et al., 2016). Currently, there is no published comprehensive theory that can explain why certain factors across different cognitive interventions have useful outcomes, even though reviews have identified factors that have been more effective than others (see Jacoby & Ahissar, 2013).

Our goal is to go beyond this pioneering work on cognitive interventions by identifying the specific factors required to induce long-term broad cognitive development in older learners (as well as younger learners). We hypothesize that interventions including the six aforementioned factors will enhance training effects well beyond current limits. According to CALLA, a large variety of tasks potentially could encourage aging adults to favor long-term adaptability over short-term efficiency, including music, art, and new language lessons (Antoniou, Gunasekera, & Wong, 2013; Bugos et al., 2007; Noice et al., 2014; Park et al., 2014), and perhaps certain types of video games (Anguera et al., 2013; Boot, Champion, Daniel, & Charness, 2013; Deveau, Jaeggi, Zordan, Phung, & Seitz, 2015), as long as they include the six factors.

Open-minded input-driven learning can be implemented via any activity that increases exposure to novel environments and tasks outside of the participant's comfort zone, while decreasing routines. Many creative arts and language interventions have incorporated this factor (e.g., learning to differentiate new sounds in a foreign language; Bak, Long, Vega-Mendoza, & Sorace, 2016; Noice et al., 2014). We propose that learning new skills is a critical factor for cognitive growth because it could train the learner how to optimally engage basic cognitive abilities to produce appropriate responses in a novel situation. Cognitive abilities themselves are a double-edged sword (e.g., some situations benefit from cognitive control, while others do not; Amer et al., 2016; Thompson-Schill et al., 2009). Perhaps instead of using isolated tasks to train specific abilities in specific contexts, cognitive training interventions could engage basic cognitive abilities in multiple contexts across different domains (i.e., broad learning) to improve training outcomes (c.f., Deveau et al., 2015). When the learner knows what is relevant and irrelevant for a given task and has practice engaging with relevant information and inhibiting irrelevant information in a variety of situations, many basic cognitive abilities may naturally increase on a given cognitive measurement (e.g., flanker task, n-back task). We hypothesize that the more novel, multi-faceted, and difficult the trained skills are for the aging learner, the larger the effects would be. Young learners are immersed in complex environments that challenge them on a daily (and even hourly) basis. However, there is a caveat to this hypothesis: the learning experience cannot be too novel or complicated (i.e., optimal person-environment mismatch; Lövdén et al., 2010). If the learning experience is too difficult or intense, the learner may withdraw to learning only easy tasks, or refuse to learn completely (e.g., refusing to learn how to use a smartphone because it seems too difficult to use). The scaffolding instructor is important here, because she would "break down" the difficult to-be-learned items into manageable pieces.

Scaffolding allows learners to experience novel situations with a tolerable amount of difficulty, which may be a critical factor mediating whether aging adults learn new information. To sustain scaffolding, the to-be-learned skill would have to be difficult to learn and master, such as learning a new language, learning to play tennis, or learning to play an instrument (Bak et al., 2016; Marzorati, 2016; Merzenich, 2013). Recent cognitive training interventions have introduced one aspect of scaffolding as a factor: personalized cognitive training that adapts its difficulty level depending on the trainee's trial-by-trial responses (e.g., Mishra et al., 2014). These "scaffolding" techniques increase difficulty levels, but not always to help the learner independently complete difficult tasks that they otherwise would not be able to complete (i.e., the goal of scaffolding during child development). In addition, these automated computer tasks do not involve an expert teacher, from whom infants, children, and young adults typically learn. Interventions with older adults may benefit from having a live instructor to scaffold aging learners' abilities (Noice et al., 2014). Younger learners tend to find live instructors more engaging than videos of instructors, typically leading to better learning outcomes (e.g., Kuhl et al., 2003). Previous training studies show that older adults can benefit similarly from learning from people (e.g., peers, teachers) as younger learners do (e.g., Margrett & Willis, 2006; Stine-Morrow et al., 2008). Self-scaffolding and self-monitoring (e.g., Dunlosky et al., 2007; Mishra et al., 2014) may be a useful alternative if teachers are not viable in the older adult's environment. However, the amount, nature, and maintenance of the gains may be limited with self-monitoring depending on the learning task. Future research should determine which interventions are best suited for live instructors vs. computerized adaptive programs, given that interventions with live instructors are often more expensive than those with computerized programs.

Growth mindset and a forgiving environment can be implemented in various ways (Dweck, 2006), although research on this topic has only been conducted with children, adolescents, and young adults. Interventions could include lectures on these two factors, providing evidence to the learners that challenge negative stereotypes (Yeager & Dweck, 2012). It may be initially difficult to induce a growth mindset and forgiving environment in aging adults due to persistent negative stereotypes (e.g., Levy et al., 2015; Nelson, 2005). However, these factors will likely enhance and prolong the effectiveness of even a short intervention via cascading effects after the intervention. For example, older adults may feel more confident when learning new skills, and continue to seek stimulating opportunities that they otherwise would avoid.

A serious commitment to learning (i.e., learning for survival), which also may be loosely related to a sense of purpose for older adults (e.g., Boyle et al., 2012), is critical for cognitive development. The natural environment can impose serious commitments on older adults, such as learning sign language to be able to communicate with one's deaf grandchild, or downsizing and moving to another state or country. For adults, the seriousness of the commitment can be elicited via an internal drive related to personality (Duckworth & Gross, 2014; Nemmi, Nymberg, Helander, & Klingberg, 2016), the perceived consequences of not adapting to the new environment, and via a desire to give back to and help their community (e.g., Carlson et al., 2009). If the aging adult does not have a strong internal drive to learn, interventions integrating external consequences or reinforcement and/or emphasizing the community could help. This type of serious commitment is rarely seen in current approaches to cognitive interventions (although see Carlson et al., 2009). In terms of external reinforcement, commitment may be elicited via rewards for completing intense learning schedules, which could complement and nurture intrinsic motivation. Cognitive development with far transfer based on novel input can require years to achieve, requiring learners to sustain this serious commitment as a lifestyle throughout the lifespan.

In terms of learning multiple skills simultaneously, compared to the intensity of the natural learning tasks faced by infants (e.g., simultaneous visual, auditory, motor, social, and tactile development), adult cognitive interventions are relatively diluted. While learning one skill (e.g., learning to play the piano) is better than learning no skills, learning two or more skills (e.g., piano and dancing) will likely enhance intervention effects. Some interventions have found that training multiple skills (e.g., sequential photography and quilting classes for 7 weeks each) leads to worse cognitive outcomes compared to training only one skill (e.g., photography classes for 14 weeks; Park et al., 2014). However, interventions requiring participants to learn multiple skills may initially require more time and effort compared to learning only one skill, and may benefit from simultaneous training (e.g., simultaneous photography and quilting classes for 14 weeks each). We hypothesize that the participants would experience larger payoffs in the long term after learning many new skills at the same time. Learning a new skill engages the interaction of various domains within the learner system (e.g., learning to play a complex piano piece naturally incorporates shifting, increased working memory load, increased speed of processing, etc.; Bugos et al., 2007), and learning multiple skills should enhance these effects and encourage far transfer (i.e., generalization to untrained skills; Barnett & Ceci, 2002). Our framework predicts that far transfer can be achieved by learning a variety of complex skills with underlying parallels (Carlson et al., 2012; Wymbs et al., 2016).

Future work should systematically investigate how all of these factors causally impact cognitive development in aging adults in the natural environment (e.g., immersive context vs. classroom; Kroll, Dussias, Bice, & Perrotti, 2015; see also immersion vs. home-based individual training, Stine-Morrow et al., 2014) and in well-controlled settings (e.g., lab-based experiments). One of the benefits of our proposed interventions is that they are scalable, similar to physical exercise (see Merzenich, 2013), and therefore can be applied in smaller or larger doses depending on individual requirements. However, as in infancy and childhood, all of the six factors are required because they interact to provide the learner with the best chance of cognitive development. Therefore, interventions that only include one or some of the factors may not be as successful as those including all of the factors.

D. Theoretical considerations

There are five additional theoretical considerations for our framework: 1) critical periods for neuroplasticity, 2) other cognitive development factors not included in CALLA, 3) cascading effects, 4) when to intervene, and 5) individual differences. First, some may be skeptical of the efficacy of the proposed training and our overall framework based on the belief that infants and children are much more "plastic" compared to older adults and that the window for the "critical or sensitive period" for neuroplasticity has closed by aging adulthood. This point of view was originally based on research demonstrating early critical periods in low-level vision (Merzenich, 2013), as well as other areas of cognitive development (e.g., second language acquisition; Johnson & Newport, 1989). This point of view underlies common sayings such as “old dogs can’t learn new tricks” and “use it or lose it.” However, recent cognitive aging research is questioning the absolute aspects of these global assumptions (e.g., Hertzog et al., 2009; Metcalfe, Casal-Roscum, Radin, & Friedman, 2015), especially given the wide variety of neural functions beyond low-level vision. While younger and older learners do have very different neurobiological profiles, plasticity does seem to be possible in adulthood, and we are only beginning to understand how plastic adult brains actually are (see Merzenich, 2013). Our framework proposes that interventions aiming to improve adult cognitive capacities have been underestimating known limits due to the omission of some or all of the six factors for cognitive development.

Second, we fully acknowledge that there are many learner and environmental factors that are important for child development and may contribute to adult cognitive development. Mitigating cognitive decline via cognitive development likely requires a favorable lifestyle approach that includes a number of factors working together to encourage cascading patterns of positive thoughts and actions (Friedman & Martin, 2011; Küster et al., 2016; Marzorati, 2016). An aim of this framework is to inform cognitive interventions with aging adults to induce a lifestyle change. There is a tradeoff when designing interventions, such that including too few factors may lead to weak effects, and including too many factors may be impractical to administer the intervention. We believe the proposed six factors can be implemented in a unified intervention. Moreover, we have not included other possible factors in CALLA, mainly because these other factors may be able to be triggered by the six proposed factors or may be inappropriate or too difficult to apply to aging adults. For example, physical activity is important for cognitive development, but is not included in CALLA as a separate factor because all of the six factors can be applied to both physical and cognitive activities. Perhaps learning new challenging physical skills would benefit the learner more than repeating familiar unchallenging exercise routines (Marzorati, 2016), while any amount of exercise would benefit the learner. Also, imitation and play are critical for child development, but perhaps are not as appropriate for adult learning, although aspects have these concepts have been included in CALLA (e.g., open-minded input-driven learning). Guided play, for example, involves a learner actively exploring her environment, and the teacher constraining the learning space in some way (Weisberg et al., 2016). Finally, the idea of the "active learner" with a sense of autonomy is entirely compatible with our framework. Perhaps engaging in our proposed six factors could encourage the learner to be "active" and develop a sense of autonomy (Weisberg, Hirsh-Pasek, Golinkoff, Kittredge, & Klahr, 2016; Yeager & Dweck, 2012). Although our framework overlaps with other frameworks for learning in childhood and adulthood (e.g., Deveau et al., 2015; Golinkoff & Hirsh-Pasek, 2016), no current model, especially ones related to cognitive aging, includes all six of these factors.

Although we focus on learner and environmental factors in this integrative review, we fully acknowledge that genetic/epigenetic factors also play a substantial role in cognitive development and aging. Importantly, cognitive developmental trajectories are impacted by interactions and cascading effects of genetic/epigenetic and environmental factors (e.g., Scerif & Karmiloff-Smith, 2005). Cascading effects (i.e., a chain of events that occur when there is a change to a system) are especially evident in the progression of developmental disabilities based on genetic disorders (e.g., Down Syndrome, Williams Syndrome; Edgin, Clark, Massand, & Karmiloff-Smith, 2015; see Raz & Lustig, 2014 for a review related to aging adults). Cascading effects may also hasten decline or improve training effects in aging adults. For example, an older adult with compromised memory may experience more errors when completing a task, which may lead her to avoid challenging situations that require high memory capacity, which may in turn exacerbate neurodegeneration. Our framework proposes that research on learner and environmental factors in cognitive aging and interventions can benefit greatly from research on early childhood experiences, where there exists a large literature on useful learner and environmental factors for cognitive development. These factors could place older adults on a developmental trajectory, instead of a declining trajectory. However, we acknowledge that developing and declining processes may interact and trade off in aging adulthood, as well as throughout the rest of the lifespan.

Besides identifying which causal factors of development and aging are most effective to target for interventions, studying the whole course of aging from birth to death can provide valuable insight into when these interventions should be implemented. Perhaps the optimal time to intervene is not when the effects are apparent (e.g., memory decline), but rather when the causes emerge to some threshold. In our framework, causes of cognitive aging (i.e., "brakes" for cognitive development and triggers for cognitive aging) would include closed-minded knowledge-driven learning, no scaffolding (i.e., a plateau of abilities), a fixed mindset, an unforgiving environment, little commitment to learning, and infrequently learning one skill (if any) at a time (Figure 1). From our review of the literature, these "brakes" seem to emerge in the general population during young adulthood. This notion suggests that, generally speaking, the best time to intervene may be during young adulthood. However, some children, and even infants, may exhibit some (perhaps all) of these "brakes" (e.g., Obradović et al., 2016). The ideas from our framework could be applied to both aging adults and typically developing younger learners, as well as perhaps learners with developmental disabilities. Future research should determine whether typical and atypical learners benefit similarly from this framework.

Finally, age-related decline is neither uniform nor universal (Mungas et al., 2010; Schaie & Willis, 2000). There is no doubt that cognitive aging is a multi-faceted process and that holistic individually tailored treatments are likely more effective than generic single-track interventions (e.g., Bredesen, 2014). Individual factors (as well as socio-cultural factors) that may play important roles in cognitive aging and intervention efficacy include (but are not limited to) personality (e.g., openness, Sharp et al., 2010), initial motivation/interest (e.g., Ennis, Hess, & Smith, 2013), level and type of reinforcement required, cultural factors (e.g., Park & Gutchess, 2006), SES, and education level. Cognitive interventions including our six factors may have cascading effects on these other factors. For example, perhaps just being immersed in a supportive environment that encourages development may lead an aging adult to seek more opportunities to learn, which may increase social opportunities and increased interest in learning new skills (c.f., Stine-Morrow et al., 2014). Despite the significant differences between children and aging adults, many aspects of how parents and teachers help struggling children can be adapted to helping older adults who may think cognitive development is impossible for them.

E. Conclusions

This integrative review introduces a novel life course conceptual framework (CALLA – Cognitive Agility across the Lifespan via Learning and Attention) that redefines healthy cognitive aging as an outcome of learning strategies and habits developed throughout the lifespan, rather than an inevitable stage of development. We argue that transitioning across the lifespan from learning broadly to becoming an expert in specific domains leads to cognitive decline initially in novel situations, and eventually in familiar situations. In particular, we argue that six factors critical for broad learning (justified by their decline across the lifespan due to specialization) may have a causal role in cognitive development throughout the lifespan, not only during childhood, and that their decline may have a causal role in cognitive aging. We provide specific predictions to test whether the six factors have a causal role in cognitive development in aging adults.

The aim of this framework is to identify the optimal methods for inducing long-term cognitive development to delay the onset of cognitive decline or mitigate existing decline in aging adults. By adopting a full lifespan approach (from infancy to aging), our framework provides a deeper understanding of the etiology and course of cognitive aging, as well as predictions for mitigating decline via cognitive development. Reconceptualizing cognitive aging as a developmental outcome opens the door for new interventions that could dramatically improve the cognitive health and quality of life for aging adults. We agree with others that cognitive development as a function should not be restricted to the first 20 years of the lifespan, but rather could occur throughout the lifespan (see Hertzog et al., 2009). The same broad learning experiences that promote children's growth and development may very well benefit aging adults. Our framework pushes the limits of current estimates of neuroplasticity and cognitive functioning in aging adults. By providing maximally supportive environments and encouraging older adults to engage in lifestyle approaches that encourage cognitive development, perhaps we will see that the actual upper-bounds during aging adulthood far exceed known limits.

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Figure 1. The graphic illustration of our novel theoretical life course framework (CALLA – Cognitive Agility across the Lifespan via Learning and Attention). We propose that broad learning can be triggered by six learner and environmental factors, and that it favors long-term adaption to novel situations. By contrast, specialization allows for efficiency in familiar environments, but ultimately reduces adaptation to novel situations, and perhaps leads to cognitive decline. Our framework encourages cognitive agility, which is achieved via a balance of broad learning (long-term adaptation) and specialization (maximizing short-term efficiency). CALLA predicts that restoring this balance in aging adults, particularly via increasing broad learning, will promote long-term cognitive development.