Exercising the brain to avoid cognitive decline: examining the evidence

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Dementias and related cognitive disorders of the brain are strongly age-associated and prevalence is expected to rise dramatically with a rapidly aging population. As a result, there has been increasing attention on the prevention and treatment of cognitive decline associated with these conditions. A number of approaches have been designed to maintain and strengthen the cognitive capacity of the healthy, as well as the pathologically damaged brain. Evidence suggests that despite advancing age, our brains, and thus our cognitive functions, retain the ability to be maintained and strengthened through the biological process of neuroplasticity. With this opportunity, a new commercial field of 'brain fitness' has been launched to bring to the market training exercises and games that maintain and strengthen cognitive abilities in adulthood. However, the majority of brain fitness methods and products now marketed and sold to consumers have scant scientific evidence to support their effectiveness.

Rationale behind brain exercise to avoid cognitive decline

Increasing attention is being paid to the health, social and economic challenges and opportunities posed by a rapidly aging population. In recent decades, given the projected expansion of the number of individuals who will develop dementia, it is becoming increasingly important to develop comprehensive approaches to primary, secondary and tertiary prevention of dementia and related disorders. As the normal aging process is also strongly associated with brain changes that lead to a weakening of some select cognitive domains in healthy persons, there has been growing interest in finding methods to 'keep our brains sharp' by maintaining or enhancing cognitive performance [1]. In addition, as age is the pre-eminent risk factor for the development of pathological brain alterations giving rise to dementia, there is an increasing focus on prevention and treatment including the use of techniques that maintain or strengthen cognition [2]. Not surprisingly, interest among the consumer public in learning how to prevent cognitive loss and how to strengthen cognitive abilities in mid and later life appears to be steadily rising. This has led to the emergence of a new 'Brain Fitness' commercial industry in which structured, live cognitive training programs, computerized games, internet-based course work and other 'products' are being marketed and sold to consumers [1]. Whether these and other activities have been rigorously and reliably demonstrated to enhance cognitive skills and functional abilities in healthy adults as well as individuals with severe acquired cognitive deficits, such as mild cognitive impairment and dementia, remains controversial and is the central subject of this article. Despite this caveat, ongoing scientific advances in various research fields do support the potential for neural connectivity to be malleable throughout the lifespan. Specifically, enhanced understanding of the biological process of neuroplasticity and a retained capacity in late life for neurogenesis may provide the rationale for the continued development of training techniques to maintain and strengthen cognitive performance at any age. As a result, the scientific-based potential of 'cognitive exercise' and the accompanying era of a commercial 'Brain Fitness' marketplace have most certainly now arrived.

Normal & pathological cognitive aging

Over the last few decades, a large body of research has been conducted to identify those changes in cognition that represent the normally aging brain by contrast to those that may be evidence of brain pathology [3]. The areas of cognition that are often examined in this context include memory, language, visuospatial ability, speed of information processing, attention and executive functioning. To assess these different domains, neuropsychologists use a broad portfolio of testing paradigms that tap into various cognitive functions. As it is beyond the scope of this article to review these specific methods, there are a number of very comprehensive references for the interested reader [4]. Despite the conclusions that have been drawn from the literature in normal aging and cognition, it is important to recognize some caveats. The majority of

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research in this area has been cross-sectional in nature, comparing one age group's performance to another. Any differences between younger versus older participants could be in part, owing to cohort-specific effects. Further longitudinal research involving specific age cohorts would be informative in this regard. In addition, much of the data reported to support age-related changes in cognition describe mean group differences in test performance. However, great individual variability in cognitive ability is often seen within specific age groups.

Normal aging & cognition

Different types of cognitive abilities tend to be grouped into categories or domains which vary in the extent of age-related change. Table 1 provides a rough summary of age-related changes in different domains of cognition. Although theorists debate about the amount of overlap between different cognitive abilities, some researchers have characterized a general pattern of age-related changes in cognition in terms of crystallized and fluid intelligence [5]. Fluid intelligence is the ability to analyze and solve novel problems, independent of acquired knowledge. It includes problem-solving skills, abstract reasoning, learning and working memory, and is more susceptible to aging compared with crystallized intelligence (Cf) [6]. Cf refers to the ability to use acquired skills and knowledge through educational and cultural experiences. It includes the ability to formulate general knowledge/information, vocabulary, reading comprehension, analogies and the ability to reason using words and numbers. Whereas Cf is either stable with age or may actually continue to improve over time, fluid intelligence may be especially vulnerable to aging [6].

Although a number of cognitive domains have been characterized, fervent debate continues regarding the distinction between the domains, the type and magnitude of age-related changes experienced within each domain and the underlying mechanisms for such change. Regarding pathological forms of aging, it is important to consider how different cognitive functions are affected in similar ways as normal aging or whether certain functions are uniquely affected by disease.

Mild cognitive impairment

Mild cognitive impairment (MCI) is an acquired disturbance in cognition without resultant impairment in daily functioning. While a variety of subtypes of MCI have been described, the most common form appearing in the literature is the MCI-amnestic subtype (aMCI) [7]. This represents a disturbance of memory with little to no other cognitive impairment and has shown to be a significant risk factor for the eventual development of dementia. Many researchers believe aMCI to be a prodromal condition of Alzheimer's disease (AD) [8].

Dementia

Dementia is a syndrome of acquired and persistent decline in memory and other realms of cognitive performance leading to functional disability. The most common cause of dementia is AD, accounting for approximately 50–75% of all cases [2]. However, postmortem studies suggest that many cases are in fact 'mixed dementia', a combination of AD and vascular dementia. It is widely believed that cerebrovascular disease is the second most common cause of dementia (vascular dementia). Other causes include dementia with Lewy bodies, frontotemporal dementia, trauma, metabolic abnormalities, nutritional deficiencies and infections of the CNS. A host of studies have demonstrated that dementia owing to AD may be prevented by cognitive stimulation, engagement in leisure activities, level of work complexity and educational attainment.

Whether these three states of cognitive function lie along a continuum remains to be elucidated. However, research demonstrates that linear and nonlinear changes in various cognitive domains, including verbal memory and fluency, visuospatial abilities and psychomotor speed, precede a diagnosis of MCI and dementia by several years [9,10]. Thus, if states of cognitive function do follow a continuum, at what point is brain structure and function malleable?

Brain plasticity & reserve theory

Neurogenesis & neuroplasticity

Although once considered fixed and unable to regenerate or reorganize, it is now well known that cells in the adult rodent and mammalian brain are dynamic and modifiable [11,12]. Neurogenesis is the ability of the brain to generate new cells [11], whereas neuroplasticity refers to the capacity of the brain to change physical structure (i.e., reorganization of neuronal networks) and function in response to environmental attributes or factors [13]. The neurobiological basis for the notion that we can impact (protect or enhance) cognitive function by modifying experience is rooted in the concept of neuroplasticity.

Table 1. Description of various cognitive domains and associated effects of age in adulthood.

Domain	Description	Example	Common measures	Effects of age	Cf/Gf
Memory					
Declarative	The ability of a person to 'declare' or recite evidence of memory ability				
– Episodic memory	Recalling information about prior experiences, events and episodes	Recalling the details of recent conversations or where you placed your keys yesterday	CVLT, logical memory	↓[†]	Gf
– Semantic memory	Knowledge, facts and meanings	Recalling facts or the name of familiar persons	NART, vocabulary tests	= (possibly ↑) (↓for semantic dementia)	Cf
– Prospective memory	Remembering to perform intended actions at the appropriate moment in the future; 'remembering to remember'	Remembering to take medication or attend upcoming appointments	McDaniel and Einstein paradigm, virtual week	↓ (laboratory-based tasks) = (possibly ↑ for real-world tasks)	
– Working memory	Temporary maintenance and manipulation of information	Maintaining a phone number or mental arithmetic	Digit span, reading span, n-back or corsi blocks	= primary/short-term ↓ working memory, especially visuospatial	Gf
Nondeclarative	Tacit knowledge or lack of awareness				
– Procedural memory	Motor memory	How to ride a bike or play piano	Pursuit rotor task, serial reaction time task, mirror tracing task or weather prediction task	=	
– Implicit memory	Behavior affected by the past with awareness	Read words (bone) and then complete word fragment (b_n_) with first word that comes to mind	Priming	=	Cf
Attention					
Selective attention	Focusing on relevant information; ignoring irrelevant information	Listening to your friend and not the person at the next table	Cocktail party effect; reading with distraction	↓	
Vigilance	Concentration, focusing on relevant information and ignoring irrelevant information for extended periods of time	Monitoring the gas gauge or cookies in the oven	Continuous performance task	↓	
Divided attention	Performing or switching between two tasks at the same time	Driving while conversing; performing a memory or attention task while monitoring digits	Dual-task paradigms (e.g., remember words, monitor for two odd digits presented in succession)	↓	
Processing speed					
Psychomotor speed	Motor or physical response	Press a button when a stimulus appears	Simple choice reaction time	↓	

Cf and Gf reflect tasks or abilities thought to capture Cf and Gf, respectively, and are only included for those domains that clearly fall into one or the other category.
[†]Declines may be explained by undiagnosed preclinical dementia [78].
Cf: Crystallized intelligence; CVLT: California verbal learning test; Gf: Fluid intelligence; NART: National adult reading test.

Table 1. Description of various cognitive domains and associated effects of age in adulthood.

Domain	Description	Example	Common measures	Effects of age	Cf/Gf
Processing speed (cont.).					
Information processing	Processing information and making decisions as fast and as accurately as possible	Press yes if the letter string is a real word or no if it is a nonword	Lexical decision, mental rotation or enumeration	↓ (i.e., 'general slowing'), especially visuospatial	Gf
Executive functions					
Planning	Plan, organize, initiate and sequence activities in the performance of a complex task	Organizing a series of steps to pick up items from grocery store	Tower of Hanoi	↓	Gf
Mental flexibility	Rapidly shift or change an approach to a task as the situation demands	Playing complex video games (e.g., first-person shooters)	Wisconsin card sort	↓	Gf
Reasoning	Higher order strategy and conceptual formulation, information manipulation and abstract thinking	Understanding analogies; solving problems	Raven's matrices	↓	Gf
Inhibition	Interference or conflict resolution or withholding an inappropriate response	Resisting dessert when trying to lose weight	Stroop test	↓	Gf
language/visuospatial abilities					
Language (verbal) abilities	Both expressive and receptive components and the ability to write and read	Read a book, write about it or talk about it	NART, vocabulary, reading comprehension	= (possibly ↑)	Cf
Visuospatial abilities	Mental imagery, mental rotation, distance judgments or spatial/directional relations	Driving	Drawing, copying, assembling block designs, Hooper Visual Organization test	↓	Gf

Cf and Gf reflect tasks or abilities thought to capture Cf and Gf, respectively, and are only included for those domains that clearly fall into one or the other category.
†Declines may be explained by undiagnosed preclinical dementia [78].
Cf: Crystallized intelligence; CVLT: California verbal learning test; Gf: Fluid intelligence; NART: National adult reading test.

Neuroplasticity: evidence from animal models

Animal models provide a wealth of information on the neurobiological correlates of age-related brain dysfunction. Canine studies demonstrate that the brains of aged dogs accumulate Aβ, which correlates with cognitive impairment [14] and further display increased oxidative damage [15], decreased myelination [16] and neuronal loss in the hippocampus [17]. Rodent data suggest that corticocortical circuitry deterioration may result from factors including demyelination [18], decreased neurotransmission (e.g., *N*-methyl-D-aspartate receptor binding) [19] and endocrine dysregulation (e.g., of glucocorticoids or estrogen) [20,21]. Finally, monkey data demonstrate age-related loss of spines on pyramidal cells and decreased density of synapses in the prefrontal cortex, all of which correlate with cognitive impairment [22] .

Initial insight into the brain's capacity of neuroplasticity stems from the plethora of animal research describing the effects that occur in the brain of the adult rodent with the provision of a more complex living environment versus a simple cage. The 'enriched environment' is a large cage that includes items such as toys, tunnels and a running wheel, all of which are considered to create cognitive stimulation. Studies show that environmentally enriched adult rodents display an increase in brain synaptic density and numbers of synapses, enlarged dendritic length, increased dendritic branching and the creation (neurogenesis) and maturation of new neurons and connections [23,24]. Presumably, several of these changes are mediated by environment-induced increases in neurotrophic factors including brain derived neurotrophic factor and nerve growth factor [13,23]. Correlated with these changes is enhancement of the rodent's motor and cognitive performance.

The effect of environmental enrichment has also been tested in transgenic mice models of AD. Following a 30-day enriched housing study, Herring and colleagues found that transgenic CRND8 mice that initially display reduced neurogenesis compared with wild-type mice exhibited enhanced cell proliferation and neurogenesis in the hippocampus [25]. Other studies have demonstrated improvements in cognitive function with reductions in Aβ plaque burden and amyloid angiopathy following enriched living [26,27], and reductions in hyperphosphorylated tau and oligomeric Aβ, two hallmarks of AD [28]. These studies highlight the possibility that environmental enrichment, and by extension, cognitive training may be beneficial in diagnosed dementia patients by improving or stabilizing cognitive function.

Cognitive & brain reserve in humans

The concept of reserve refers to a threshold model of vulnerability to injury or the cumulative effects of aging. For example, there appears to be significant variability among individuals in the clinical consequences and severity of disability associated with a similar level of pathological burden within the brain [29]. This has been demonstrated in AD, stroke and traumatic brain injury. Stern and collaborators have argued that although the terms 'brain reserve' and 'cognitive reserve' are often used interchangeably, they each represent a different concept [30]. Specifically, in their framework brain reserve refers to the physical endowment of the brain in terms of cranial capacity (a proxy for brain size), the density of neurons and the degree of connectivity between them (synaptic density). Cognitive reserve, on the other hand, refers to the potential to increase the efficiency and capacity of existing neural pathways and/or to recruit new pathways that are not typically used to accomplish a task. Several perspectives have been delineated to link theories of brain and cognitive reserve. One perspective is that of computational redundancy and flexibility [31]; an individual with high reserve will display more flexible cognitive processes (i.e., high cognitive reserve) and a greater number of redundant neural pathways (i.e., high brain reserve) and thus, will experience a longer asymptomatic period despite neurological insult. Furthermore, two individuals with the same level of brain reserve may display differential symptoms following brain insult depending on complexity and flexibility of their cognitive processes.

Thus, the greater the degree of anatomical brain reserve that exists, the higher the threshold of pathological burden that needs to be crossed before brain changes are significant enough to lead to clinical features of illness (i.e., cognitive impairment). It has been demonstrated that brain reserve can be influenced and is not merely fixed: a variety of studies have demonstrated that aerobic physical exercise leads to morphological changes such as increased brain volume within the rodent as well as the adult human [32]. It is less clear whether cognitive exercises can induce the same type of structural alterations. However, Stern and colleagues have posited that intellectually enriching activities throughout life (education, mentally

challenging work and certain leisure activities) and perhaps, as well, structured cognitive training could enhance cognitive reserve [33]. As a consequence, cognitive reserve could theoretically modulate the potential impact of age-related and pathological brain changes on cognitive performance. A number of human studies have addressed whether enhancement of reserve is possible through cognitive exercise. The following section of the article reviews studies that have assessed whether cognitive training techniques can enhance cognitive function and possibly alter reserve in later years.

Protecting brain health in late life: epidemiological evidence

A number of studies have examined how participation in mentally stimulating activities throughout adult life can protect cognitive function in older age through impacting brain reserve, cognitive reserve or both. These studies can be grouped into two types based on their design: observational and experimental. Findings of both types of studies have provided support for the development of efforts to further methodically strengthen cognition through formal interventions. First, we review epidemiological evidence for the potential of various lifestyle factors to protect brain health in late life. Table 2 summarizes the epidemiological studies reviewed below. Verghese and colleagues studied whether participation in leisure activities reduced the risk of incident dementia in community-residing older adults [34]. The authors found that leisure activities such as reading, playing board games, playing musical instruments and dancing were all associated with a reduced risk of developing dementia. Specifically, a one-point increment in a cognitive activity score was significantly associated with a reduced risk of dementia (hazard ratio: 0.93; 95% CI: 0.90–0.97). By contrast, a one-point increment in physical activity score was not associated with reduced incident dementia. The authors concluded that controlled trials are required to prospectively assess the effects of cognitive leisure activities on the risk of dementia. Karp and coworkers reported on the association of work complexity during midlife and dementia risk after 75 years of age [35]. The investigators reported that lower dementia risk was associated with complexity of work as measured by the use of workplace related data (relative risk: 0.85; 95% CI: 0.75–0.95) and engagement with people (relative risk: 0.88; 95% CI: 0.29–0.95). However, the association was no longer statistically significant after controlling for education. The greatest degrees of complexity of work that involved analyzing, coordinating and synthesizing data was associated with reduced dementia risk, even among lower educated participants (relative risk: 0.52; 95% CI: 0.29–0.95).

Wilson and colleagues studied the relationship between participation in cognitively stimulating activities that involved information processing and the risk of incident dementia in a cohort of older Catholic nuns, priests and brothers without dementia at baseline [36]. Assessment of cognitive activity used frequency of engagement in common pursuits including viewing television, listening to radio, reading newspapers, magazines and books, playing games such as cards, checkers, crosswords and other puzzles, and visiting museums. Proportional hazards model demonstrated that a one point increase in cognitive activity score was associated with a 33% reduction in risk for AD (hazard ratio: 0.67; 95% CI: 0.49–0.92). In their analysis of additional random-effects models, they reported that a one point increase in cognitive activity was associated with reduced decline in global cognitive function by 47%, working memory by 60% and perceptual speed by 30%. The authors concluded that on average, a person reporting frequent cognitive activity at baseline (90th percentile) was 47% less likely to develop AD than a person with infrequent activity (10th percentile).

In a longitudinal study evaluating the relationship between engagement in cognitive demanding activities and the degree of cognitive decline experienced over time, Wilson and colleagues reported on a cohort of 4000 community residing older adults [37]. The investigators reported that more frequent cognitive activity was associated with reduced cognitive decline during follow-up. Specifically, a one point increase in cognitive activity score was associated with an approximate 19% decrease in the annual rate of cognitive decline. The authors concluded that frequent participation in cognitively stimulating activities is associated with reduced cognitive decline in older persons.

Fritsch and colleagues examined the relationship between participation in novelty-seeking leisure activities and the risk for developing AD [38]. Using a case–control method, they compared the reports of surrogates of AD patients (n = 264) with a control group of neighbors and friends of the cases plus a randomly selected group of community members (n = 545) regarding prior participation in different types of mental leisure activities, especially those involving 'novelty seeking'. Factor analysis of the activity

Table 2. Epidemiological studies that assess the association between lifestyle factors and cognitive function in late life.

Study	Sample size (n)	Lifestyle factors assessed	Statistically controlled factors	Follow-up (years)	Significant factors	Generalization outcome measures	Ref.
Verghese *et al.*	469 healthy older adults	Cognitive activity, physical activity	Age, sex, education, physical morbidity and baseline cognitive status	5	Leisure factors (reading, playing games, musical instruments or dancing)	Reduced risk of dementia	[34]
Karp *et al.*	931 healthy older adults	Occupation complexity, social engagement	Education	6	More complex work and engagement with people	Reduced progression to dementia[†]	[35]
Wilson *et al.*	801 healthy older adults	Cognitive activity (e.g., reading and playing games)	Age, sex, education and baseline cognitive status	4.5	Cognitive activity (e.g., reading and playing games)	Reduced cognitive decline and progression to dementia	[36]
Wilson *et al.*	4000 adults	Cognitive activity (e.g., reading and playing games)	Baseline level of cognition, age, sex, race and education	5.3	Cognitive activity (e.g., reading and playing games)	Reduced cognitive decline (e.g., episodic memory, immediate and delayed recall or perceptual speed and the MMSE)	[37]
Fritsch *et al.*	809 adults (including 264 surrogates of AD patients)	Mental leisure activities (novelty seeking, exchange of ideas and social activity)	Age, gender, ethnicity, education and occupation	–[‡]	Novelty seeking, exchange of ideas	Reduced risk of dementia	[38]
Helzner *et al.*	283 AD patients	Leisure activity	Age, sex, ethnicity, education and baseline IQ	5	Intellectual activity	Higher baseline cognitive status, fewer physical comorbidity (including stroke), but faster decline postdiagnosis	[39]

[†]Effects were positive, but no longer significant after statistically controlling for education.
[‡]Data not available: a case–control method with logistic regression was used.
AD: Alzheimer's disease; MMSE: Mini-mental status exam.

questions identified three activity factors of significance: novelty seeking, exchange of ideas and social activity. Logistic regression analysis indicated that greater participation in novelty-seeking and exchange of ideas activities were significantly associated with decreased odds of AD. The odds of AD were lower among those who participated more often in activities involving the exchange of ideas (odds ratio [OR]: 0.695; 97.5% CI: 0.467–1.034) and were even lower for those participants who reported more frequent participation in novelty-seeking activities (OR: 0.248; 97.5% CI: 0.139–0.443). Finally, the investigators reported that participation in social activities did not increase or decrease the odds of being in the AD group.

Paradoxically, in a 5-year longitudinal study that assessed prediagnosis leisure activity on rate of cognitive decline in patients with AD, Helzner and colleagues reported that high leisure activity prior to AD diagnosis, especially intellectual activity, was associated with faster postdiagnosis cognitive decline [39]. Higher leisure activity was associated with higher baseline cognitive function, fewer medical comorbidities and lower stroke prevalence. Based on these and other findings [40], the authors proposed that leisure activity serves as a proxy of cognitive reserve. With enhanced compensatory mechanisms at play, individuals who engage in high leisure activity may delay the adverse effects of AD associated pathology, allowing for a longer period of

normal cognitive function [41]. However, once the higher threshold of AD pathology is met, quicker neurocognitive decline ensues [41,42].

Collectively, there is evidence for cognitive reserve in late life in that higher cognitive functioning in late adulthood is associated with a lifelong pursuit of complex cognitive activities. However, the studies reviewed above are correlational in nature and therefore one cannot be certain of the causal role of cognitive activity. Additional evidence from experimental studies (ideally randomized clinical case–control trials) provides an even more convincing case. Below, a review of the relevant studies is reported.

Cognitive training approaches to protect brain health in later life: case–control studies

Two types of training approaches

Two approaches towards cognitive training studies have been taken, compensatory and restorative. Compensatory training approaches teach new ways to accomplish a cognitive task by working around cognitive weaknesses or deficits. This is done by training strategies such as categorizing or visualizing information that is to be remembered, as well as utilizing external memory aids such as notes, calendars or other environmental cues [43]. Restorative approaches seek to strengthen specific cognitive domains in order to improve functional performance more generally. For example, participants of some studies practice memory and attention games with the hope of improving those domains in general. The idea behind restorative training is that training on one task might enhance the cognitive ability or abilities that are needed to perform similar tasks (near transfer) or very different tasks such as activities of daily living (far transfer). Whereas compensatory approaches tend to only produce near transfer effects by benefiting the specific training task or domain that was targeted by the training program, far transfer effects through restorative training are considered the 'holy grail' because they suggest cognitive functions can be enhanced beyond the specific domain of training. To date the training studies that have been conducted have used either compensatory or restorative (or both) types of approaches to assess the impact of cognitive training on brain health.

Cognitive training interventions in healthy elderly: case–control studies

In a meta-analysis of the cognitive exercise literature, Valenzuela and Sachdev conducted a systematic review of randomized clinical trials with a longitudinal follow-up [44]. Of the 54 identified studies, only seven published trials involving approximately 3000 participants, possessed eligible criteria for inclusion which included randomization, repetitive training over separate days for more than 1 week, longitudinal follow-up beyond 3 months and participation by healthy community-dwelling older adults of more than 50 years of age. Participants with any cognitive impairment, including dementia were excluded, as were individuals with a major neurological or psychiatric disorder. The major search engines included MEDLINE, PubMed and key references. The studies examined in this review focused on techniques to improve cognitive performance in reasoning, memory, information processing speed, problem-solving and attentional ability. Many of the studies included a combination of both compensatory and restorative types of cognitive training. Pre- and post-intervention scores were integrated using a random effects weighted mean difference (WMD) meta-analytic approach. The investigators concluded that cognitive exercise training in healthy older adults produces strong and persistent protective effects on longitudinal neuropsychological performance, particularly in the domains that were of major focus for the intervention. The effect size was reported as strong for cognitive exercises compared with a control condition (WMD: 1.07; 95% CI: 0.32–1.83; z = 2.78; n = 7; p = 0.006; n = 3;194). Far transfer was only reported in some of the studies. Notably, the authors concluded that although cognitive exercise demonstrated protective effects on neuropsychological function, it has yet to be shown to prevent incident dementia.

Papp and colleagues also reviewed the state of the literature on immediate and delayed effects of cognitive interventions in healthy elderly individuals [45]. Their review utilized five electronic databases: MEDLINE, Scopus, the Cochrane Collaboration, Dissertation Abstract International, PsychINFO and two registers: Current Controlled Trials and Clinicaltrials.gov. Only studies that were randomized, written in English and published after 1992 were included for evaluation. Study participants had to be healthy community residing elderly. Using these criteria, ten studies met inclusion for their meta-analysis. The authors found a post-training mean weighted effect size (Cohen's d) of 0.16 (95% CI: 0.138–0.186), which represents a small, but significant benefit of cognitive exercise. However, they concluded that the existing literature is limited by a lack of consensus

on what constitutes the most effective type of cognitive training, insufficient follow-up times, a lack of matched active controls and few outcomes demonstrating transfer of any cognitive gains to daily function or global cognition. This analysis also failed to detect any evidence that cognitive training prevents the incident AD in healthy older adults.

Included in both of the above analyses is the largest and perhaps most informative study ever carried out examining the long-term effects of cognitive training in healthy older adults: the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study. It included 2832 volunteer participants, with a mean age of 74 years and was conducted in multiple sites. Participants were recruited from senior housing, community centers, clinics and hospitals. The intervention consisted of ten small group sessions designed to train one of three cognitive areas: memory, reasoning or processing speed [46–48]. Training sessions lasted 60–75 min each and were led by a certified trainer. The memory training sessions consisted of learning mnemonic strategies (organization, visualization and association) for recalling word lists and texts (verbal material) followed by practice using those strategies. Reasoning training included learning and practicing strategies for finding and completing patterns in a letter/word series. Speed of processing training involved learning how to effectively visually search and divide attention by doing challenging tasks on a computer screen [46]. Participants were randomized into one of the three training groups or a fourth control group. In a random sample of those who completed initial training, four 'booster' training sessions were provided at 11 months and 35 months. Assessments were conducted at baseline, immediately following the intervention and then at 1, 2, 3 and 5 years follow-up. The immediate ACTIVE results demonstrated improved cognitive function in each of the three domains targeted for intervention. These improvements were maintained through 2 years of follow-up, although no far transfer effects were observed [48]. Willis and colleagues specifically reported data on the 5-year follow-up of the initial study [46]. Approximately two-thirds of the original sample was available. As compared with controls, those who had been randomized to the reasoning training conditions had less functional decline in self-reported instrumental activities of daily living (IADLs) at the 5-year mark (effect size: 0.29; 99% CI: 0.03–0.55). This effect on function was not seen in either the memory or speed of information processing groups. However, all three groups maintained the specific cognitive domain improvement initially reported at the beginning of the study. Further, the booster training for speed of information processing, but not for the other two groups, led to a significant performance-based cognitive improvement.

In summary, this study demonstrated that specific-domain cognitive training, as compared with a control condition, improves ability in specific targeted domains, which persist for at least five years in study completers. In terms of maintaining functional ability in IADLs, only reasoning training seems to have had this specific positive effect. Wolinsky and colleagues reported that the ACTIVE trial interventions also had a positive impact on well-being by mitigating decline on health-related quality of life measures. Specifically, they reported that at the 2-year follow-up, there was a protective effect demonstrated by the speed of processing, but not for the memory or reasoning interventions. However, at the 5-year follow-up, all intervention groups demonstrated a protective effect on decline in health-related quality of life [49]. This latter point is important because it suggests that, unlike many medical treatment interventions, participants in this cognitive training program did not appear to experience any negative side effects of treatment and some even appeared to have experienced an enhanced quality of life.

Mahncke and colleagues conducted a study assessing the potential benefits of a computerized cognitive training program developed by a commercial entity, Posit Science [50]. The 'experimental' group engaged in six computer-based exercises of increasing difficulty tied to gains in performance using the Posit Science Program. This involved using the program in 1-h sessions, five-times per week for 8–10 weeks. The 'active control' group accessed a computer-based educational program on how to maintain good cognitive health and were asked to recall what they had learned. The 'no contact' control group received no intervention. Compared with the control groups, the experimental group demonstrated an immediate improvement in specifically trained cognitive domains including speed of processing and a variety of verbal memory related tasks.

In a larger follow-up investigation, Improvement in Memory with Plasticity-Based Adaptive Cognitive Training (IMPACT), Smith and coworkers further reported on the efficacy of the 'Posit Science Brain Fitness Program' in

community residing older adults [51]. Participants were randomly assigned to two groups: an experimental group and an active control group. The experimental group used the Posit Science computerized training method while the active control group used computers to view educational programs on history, art and literature and then were quizzed after each training session on the content of the programs. All participants endured 1 h of training per day, 5 days a week for a total of 8 weeks. The investigators reported that on a standard neuropsychological test of auditory memory and attention (RBANS auditory memory/attention), the experimental group demonstrated significant ($p = 0.02$) improvement (3.9 points; 95% CI: 2.7–5.1) compared with the active control group (1.8 points; 95% CI: 0.6–3.0). Therefore, the computerized training method of Posit Science resulted in near transfer effects; however, it is unknown whether these were long-lasting effects or if there were any far transfer effects on more global or everyday cognitive functions.

In addition to enhancing cognitive performance, Engviv and colleagues reported on the effects of an 8-week intensive memory training program on cortical thickness in older adult participants [52]. Compared with the controls, memory trainers displayed increased cortical thickness of the right fusiform and lateral orbitofrontal cortex, which were both correlated with improvement in source memory performance. Although only short-term effects were examined, these findings support the notion of neuroplasticity in later life, and of enhanced brain reserve following cognitive training. However, longitudinal research is needed to determine the lasting effects of cognitive training on reserve.

Although exciting prospects are emerging, more research is required to determine the most effective type of cognitive training for protecting cognitive function and producing transfer to everyday life. With regards to cognitive training interventions in populations associated with pathological aging, the need for more research is even greater. Table 3 summarizes the cognitive training studies on healthy aging as well as those involving MCI and AD populations, some of which are reviewed in detail below.

Cognitive training interventions in MCI

Kurz and colleagues explored the benefits of a multicomponent cognitive rehabilitation program in patients with MCI [53]. Their study included two active intervention groups composed of 18 patients with MCI and ten patients meeting clinical criteria for mild AD, and 12 MCI patients allocated to a waiting list control condition. Both intervention groups participated in a 4-week group format cognitive training regimen that included activity planning, training in self-assertiveness, stress management, relaxation techniques and the use of external memory aids, memory training and physical exercise. The investigators reported that after four weeks, MCI participants demonstrated significant improvements on IADL, verbal and nonverbal episodic recall and mood. However, participants with mild AD seemed to gain no measurable benefits from the program other than an improvement in verbal memory, which failed to reach statistical significance. The MCI control participants demonstrated a significant retest effect on verbal episodic memory, but no other significant changes. It is promising that individuals with MCI showed some response to the training program, but owing to the multiple factors that were trained, it is difficult to differentiate between types of training that were beneficial and those that were not.

Troyer and colleagues conducted a randomized controlled trial to evaluate the effectiveness of a multidisciplinary group-based intervention program designed to change everyday 'memory behavior' in participants with a MCI [54]. The active intervention consisted of evidence-based memory training techniques and lifestyle education consisting of ten 2-h small group sessions conducted over 6 months. The investigators reported that the active intervention group demonstrated an increase in memory-strategy knowledge and use from pretest to immediate post-test, and these gains were maintained at 3-months post-test, relative to wait-list controls. Notably, there were no group differences in memory beliefs or on neuropsychological test measures of objective memory performance. The authors concluded that individuals with MCI can acquire and maintain knowledge about memory strategies and can alter their daily memory behavior by applying this knowledge into everyday functioning.

Belleville and collaborators reported on the efficacy of cognitive training in participants with MCI and individuals with 'normal cognitive aging' [55]. The intervention consisted of teaching the participants strategies to improve episodic memory. Three tasks of episodic memory (list recall, face–name association and text memory) were used as primary outcome measures. The authors reported that, relative to a wait-list control condition, the

Table 3. Case–control studies that assess the effects of cognitive training on cognitive function in older adults.

Study	Sample size (n)	Cognitive training	Control condition	Duration (min/week)	Total sessions (n)	Follow-up (months)	Significant training and near transfer effects	Significant far transfer effects	Ref.
Ball *et al.* (ACTIVE)	2832 healthy older adults randomly assigned	Three training groups: memory strategy, reasoning and computerized speed of processing	No contact	120–150	10	24	Domain of targeted training	ADL, IADL and driving habits questionnaire	[48]
Willis *et al.* (ACTIVE)	67% of original sample	See above	See above	See above	See above	72	Domain of targeted training	IADL	[46]
Smith *et al.* (IMPACT)	487 healthy older adults	Auditory information processing (Posit Science, CA, USA)	Active	300	40–50	8 weeks	Attention, episodic memory, visuospatial abilities	Auditory memory and attention	[51]
Mahncke *et al.* (IMPACT)	182 healthy older adults	Auditory information processing (Posit Science)	Active contact and no contact	240	40	3	Attention, episodic memory, visuospatial abilities	Not reported	[50]
Engviv *et al.*	22 healthy older adults	Memory strategy (method of loci)	No contact	60	8	2	Word recognition and source memory	Volumetric changes in structural MRI	[52]
Kurz *et al.*	18 MCI and 10 AD patients	Activity planning, self-assertiveness training, relaxation techniques, stress management, use of external memory aids, memory training and motor exercise	Wait list	1320	20	1	Verbal and nonverbal episodic memory in MCI; no change in AD	ADL and mood in MCI; no change in AD	[53]
Troyer *et al.*	50 MCI patients	Memory strategy training (spaced retrieval, memory book, semantic association, logical location) within a larger mixed intervention	Wait list	25	10	3	Episodic recall, digit span and laboratory memory strategy use	Everyday memory strategy knowledge and use, multifactorial memory questionnaire	[54]
Belleville *et al.*	20 MCI patients	Memory strategy training	Wait list	120	8	2	Episodic recall of lists and face–name associations	Subjective memory and well-being	[55]
Barnes *et al.*	47 MCI patients	Auditory information processing (Posit Science)	Active	500	30	–	Attention, episodic memory, visuospatial abilities and verbal fluency	GDS	[79]

ACTIVE: Advanced Cognitive Training for Independent and Vital Elderly; AD: Alzheimer's disease; ADAS-Cog: Alzheimer's disease assessment scale-cognitive subscale; ADL: Activities of daily living; ChEI: Cholinesterase inhibitors; GDS: Geriatric depression scale; IADL: Instrumental activities of daily living; MCI: Mild cognitive impairment; MMSE: Mini-mental status exam; NPI: Neuropsychiatry inventory.

Table 3. Case–control studies that assess the effects of cognitive training on cognitive function in older adults.

Study	Sample size (n)	Cognitive training	Control condition	Duration (min/week)	Total sessions (n)	Follow-up (months)	Significant training and near transfer effects	Significant far transfer effects	Ref.
Rozzini *et al.*	59 MCI patients	Computerized training of attention, reasoning, visuospatial abilities with ChEI	No contact and ChEI alone	12	72	3	Memory, verbal fluency, Raven's matrices	MMSE, behavioral disturbances; depressive symptoms	[80]
Rapp *et al.*	19 MCI patients	Memory strategy training (cueing, categorization, chunking, method of loci) within a larger, multifaceted intervention	No contact	6	96	6	Memory functioning questionnaire, memory controllability questionnaire, episodic recall (words, stories, grocery lists, names and faces)	Profile of mood states	[81]
Requena *et al.*	86 AD patients	Computerized cognitive training with ChEI	Active	225	520	–	–	MMSE, GDS ADAS-Cog	[82]
Galante *et al.*	11 AD patients	Multidomain computer training, NPT	Active	180	12	9	Prose memory, word repetition test, Corsi blocks, Raven's matrices, digit cancellation, semantic and phonemic fluency, constructional and ideomotor apraxia	MMSE, NPI, GDS, IADL, basic ADL	[83]
Cahn-Weiner *et al.*	34 AD patients	Memory strategy training	Active	45	6	2	Verbal and visuospatial memory, verbal fluency, visuospatial processing speed	ADL	[84]
Loewenstein *et al.*	44 AD patients	Cognitive rehabilitation training	Active	90	24	3	Face–name association, orientation, object memory, change (for purchase), balancing checkbook, continuous performance test	MMSE, basic ADL, depression	[85]
Olazaran *et al.*	72 AD, 12 MCI patients	Multidomain training (pen and paper)	Active	60	103	12	–	MMSE, functional activities questionnaire, GDS ADAS-Cog	[86]

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Davis *et al.*	37 AD patients	Memory strategy and attention training	Active	60	5	–	Logical memory test, visual reproduction test, digit span test, verbal series attention test and verbal fluency test	MMSE, quality of life assessment and GDS	[87]
Tarraga *et al.*	46 AD patients	Multidomain (attention, gnosis language, memory, orientation, calculation), internet-based program within a multifactorial intervention	Active	75	72	5.5	Verbal fluency and story recall	ADAS-Cog, MMSE, rapid disability rating scale-2 and GDS	[88]

ACTIVE: Advanced Cognitive Training for Independent and Vital Elderly; AD: Alzheimer's disease; ADAS-Cog: Alzheimer's disease assessment scale-cognitive subscale; ADL: Activities of daily living; ChEI: Cholinesterase inhibitors; GDS: Geriatric depression scale; IADL: Instrumental activities of daily living; MCI: Mild cognitive impairment; MMSE: Mini-mental status exam; NPI: Neuropsychiatry inventory.

intervention effect (pre- and post-intervention difference) was significant on two of the three primary outcome memory performance measures (delayed list recall and face-name association). A significant pre-post effect was also found on measures of subjective memory and well-being. There was no improvement in the performance of either individuals with MCI or normal elderly people who were randomized to the wait-list condition. The investigators concluded that the results of this study suggest that individuals with MCI can improve their performance on episodic memory when provided with structured cognitive training.

In summary, in all three studies that enlisted individuals with MCI into a cognitive training intervention, participants benefited from the treatment in some way, including improvements in near transfer tasks (e.g., recall of lists or face–name associations) to domains as far reaching as activities of daily living and subjective measures of memory, mood and overall well-being. Although these studies suggest enhancement effects, longitudinal studies are required to determine whether interventions prevent or slow the progression to AD.

Cognitive training interventions in dementia

The results of cognitive interventions in dementia have been mixed. Clare and coworkers conducted a Cochrane Database systematic review on the effectiveness and impact of cognitive rehabilitation and cognitive training focused on improving memory for early-stage AD and vascular dementia [56]. Their review utilized the CDCIG Specialized Register, containing records from MEDLINE, EMBASE, CINAHL, PsycINFO and several other databases. For their analysis, they only included randomized clinical trials comparing cognitive rehabilitation or cognitive training interventions with comparison conditions. Ultimately, six studies met the inclusion criteria. Data from ordinal scales were treated as continuous and a fixed-effects model was applied in calculating WMD and 95% CI. The investigators reported that none of the six studies demonstrated a statistically significant effect of cognitive training interventions in any domain. However, there were indications of some modest effects in various cognitive domains that did not reach statistical significance. The researchers concluded that their findings did not provide strong support for the use of cognitive training interventions for patients with early-stage AD or vascular dementia. However, they tempered their conclusions with the observation that the number of well-controlled studies and numbers of participants was limited at the time of their analysis. In addition, none of the studies they evaluated employed an individualized cognitive training strategy that was specifically geared towards the deficits and needs of each patient.

In a more recent review, Sitzer and coworkers also conducted a meta-analysis [43]. They searched MEDLINE and PsycINFO databases to identify peer-reviewed reports of controlled trials of cognitive training for AD. Based on their inclusion criteria, 17 published articles were analyzed using Cohen's d to establish effect sizes. The authors reported that an overall effect size of 0.47 was observed for all cognitive training strategies across all measured outcomes. Mean effect sizes were higher for restorative (0.54) than for compensatory (0.36) strategies. Cognitive domain-specific effect sizes ranged from 2.16 (verbal and visual learning) to -0.38 (visuospatial functioning). The investigators concluded that cognitive training does demonstrate promise in the treatment of AD. Medium effect sizes were evident for learning, memory, executive functioning, activities of daily living, general cognitive problems, depression and self-rated general functioning. However, they cautioned that most studies report small sample sizes and use of neuropsychological test measures instead of performance-based measures of daily functioning to determine the effectiveness of the training intervention. Finally, a majority of studies employ a combination of treatment strategies that confound the ability to draw conclusions about the effect of any one specific intervention. Therefore, the effectiveness of cognitive training interventions in AD remains equivocal. Clearly more research is needed.

Nontraditional cognitive methods & alternative approaches

A variety of studies have now been published exploring the cognitive benefits of recreational activities, social networks, physical fitness and other related and integrated activities. The goal of these investigations is to determine whether activities that are part of everyday life may result in better transfer effects to function than standalone cognitive exercises (training workshops or computer based). Many of these investigations explore the benefit of activities that are multidimensional and that require creativity as well as new skill acquisition. Although these studies do not match the scientific rigor of clinical trials that isolate and train a specific cognitive ability, they

fulfill an important role by potentially revealing potent factors to be targeted by more controlled intervention studies in the future.

Nontraditional training

In a study using nontraditional cognitive approaches, de Medeiros and coworkers studied whether participation in an autobiographical writing workshop had positive effects on cognition [57]. A total of 18 physically and cognitively healthy seniors were enrolled in 90-min writing sessions over an 8-week period, and were taught a variety of different writing techniques. The investigators reported that participants in the structured workshop demonstrated improvements in processing speed, verbal learning and attention. Noice and colleagues studied the effects of theatre training on cognitive, emotional and physiological functions in a cohort of 124 community-dwelling seniors [58]. Participants were assigned to one of two intervention groups (theatre training and visual arts education), consisting of nine sessions over 4 weeks. There was a third, no-intervention control group. The authors reported that theatre training participants showed significant improvements over controls in memory recall, problem-solving and emotional well-being. These effects were not seen in the visual arts education group, who did not perform as well as the theatre group in problem solving and emotional well-being. After 4 months, the problem solving effects were stable and memory performance continued to improve. These same investigators conducted a related study in a sample of seniors who were less educated and of a lower socioeconomic status, residing in publicly subsidized retirement homes. These participants also demonstrated the positive impact of theatre training on cognitive performance [59].

In an ongoing pilot program called Experience Corps® [60], researchers are starting to report on the benefits of volunteering on brain health. The program provides a model that enhances physical, social and cognitive activity, which is expected to produce enhanced mental flexibility, improved working memory skills, cooperative problem solving and other cognitive and functional benefits. The initiative consists of older volunteers working within a school for grades K-3 for a minimum of 15 h per week. The work involves special areas of need within the school; literacy tutoring, behavior management and library use. In an 8-month follow-up study, Carlson and coworkers found that when compared with controls, older adults who volunteered in Experience Corps displayed a nonstatistically significant trend towards improvements in executive functions and memory [61]. However, active volunteer participants with impaired baseline executive functions showed the greatest degree of improvement in executive and memory functioning at follow-up while the similarly impaired controls declined in executive functions ability ($p < 0.05$). Carlson and colleagues assessed the benefits of Experience Corps in 'at risk' volunteers (i.e., African–American women with low level education, low income and low Mini-mental status exam [MMSE] score at baseline) [62]. Not only were cognitive improvements found in executive inhibitory processes, but intervention-specific increases in brain activity were observed in the prefrontal and anterior cingulate cortex at 6-month follow-up using functional MRI. This study suggests that engaging in stimulating activities (via volunteering) may enhance brain plasticity, and presents the possibility of mapping brain changes to behavioral outcomes.

Overall, nontraditional cognitive approaches provide some promising results; however, more vigorous randomized control studies are required in order to elucidate beneficial components of each activity and to isolate the specific cognitive domains that are being altered as a result.

Alternative approaches

Epidemiological studies show that physical activity [63,64], nutrition [65] and social engagement [66,67] may play a protective role against brain aging. Furthermore, these findings coincide with the animal literature. For example, monkey [68,69] and rodent [19,70] studies have demonstrated that caloric intake restriction may prevent age-related decrements in brain structure and function. In addition, it has been shown that the exercise component of the rodent enriched environment (i.e., the running wheel) produces additional neurogenesis effects by enabling the maturation of neuroblasts into functional hippocampal neurons [71]. These studies suggest that cognitive function may be enhanced by alternative strategies that indirectly affect brain function.

Given the important role of exercise on brain function [72,73], researchers have started to assess the combined effects of physical and cognitive activity on brain health. In a 6-month, randomized control trial, Klusmann and colleagues assessed the effects of mental and physical activity on cognitive performance in older women 70–93 years of age [74]. Women were randomly assigned to an exercise group, a computer course group or a control group. At follow-up, women

in the computer group and the exercise group demonstrated improvements in episodic memory and maintenance in working memory, compared with controls who showed a decline in cognitive performance. However, this study did not assess the interaction effect between exercise and mental activity on cognitive outcomes. In a sample of 19 middle-aged and older adults with subjective mild memory complaints, Small and colleagues reported on the combined effects of cognitive and physical exercise, stress reduction and a healthy diet on cognitive performance and cerebral metabolic activity as measured by positron emission tomography data [75]. They reported improvement in verbal fluency with correlated changes in prefrontal cortical metabolism, perhaps indicating enhanced cognitive reserve. Finally, the investigators concluded that such a lifestyle program may result in enhanced cognitive efficiency of a brain region involved in working memory.

In summary, more research is needed to understand what constitutes the most effective type of cognitive training, the long-term retention of training effects and whether training can demonstrate transfer of cognitive gains to daily function or global cognition. Initially, promising associations were found between a reduced level of cognitive decline in late-adulthood and a life-long pursuit of cognitive engagement, which supports the idea of a brain/cognitive reserve. However, the limited number of well-designed trials that fully test the nature of benefits attainable from cognitive training interventions prevent one from definitively concluding that it is possible to maintain or improve cognitive function, or prevent cognitive decline associated with healthy or pathological aging. Furthermore, additional research is required to assess other life-style domains (e.g., exercise and nutrition) and how they may interact with cognitive training strategies on brain function. Nonetheless, it is important to note that there is also 'little evidence to suggest that interventions designed to improve cognitive function either worsen it or produce unwanted side effects' [76]. Additional research is also needed to determine the intervention-based neurological changes that may occur: whether these changes are short or long-lived and whether they may be observed in both healthy and patient groups.

Rise of the commercial brain fitness movement

Despite the need for more research to determine intervention efficacy, a new market of 'brain fitness' products have already been developed for the consumer public, the corporate training sector, insurance companies, schools and related educational programs. These products include web-based cognitive exercise programs, DVDs, corporate training programs and recreational games played online or on hand-held devices. Very few of these products have been scientifically tested and fewer still have reported their findings in peer-reviewed journals. Yet advertisements for various products may make rather bold claims, such as 'improve memory by 10 years'. When scientific studies do attempt to evaluate the effectiveness of cognitive training programs for improving cognitive function, they may reveal nothing more than marketing myths. For example, Owen and colleagues recently conducted an internet-based study on the benefits of playing video games similar to the Nintendo DS™ Brain Age games for producing improved cognitive function [77]. A total of 11,430 volunteers, including experimental (n = 8692) and control (n = 2738) participants, aged 18–60 years practiced a variety of video games designed to train functions such as reasoning, memory and attention over 6 weeks. Although improvements were found in the specific trained cognitive tasks, the authors reported no evidence for transfer effects of training to cognitively related untrained tasks. It is important to mention a number of limitations with the study. The study did not enroll adults over 60 years of age, there were substantial dropout rates (approximately 80%) and participants only had to perform at least two 10-min training sessions over 6 weeks in order to be included in the analysis. Therefore, the results of the Owen *et al.* study should not be taken as definitive evidence against the possibility that cognitive training can provide benefits to cognitive function in later adulthood. Future research is required to determine the effectiveness of various 'brain training' video games.

Despite the lack of substantiated claims for cognitive training benefits, the brain fitness commercial industry is rapidly growing worldwide with reported sales of US$100 million in 2005 having grown to $265 million in 2008. It is anticipated by leading brain fitness industry analysts that this market could achieve between $1 billion and $4 billion in revenue by 2015 [56].

Conclusion & future perspective

It is anticipated that as the population continues to age rapidly across the globe, cognitive disorders such as AD will pose even greater public health challenges. As a result, increasing attention is being devoted to methods to help prevent age-associated cognitive decline. At the

same time, new scientific insights into how cognition changes with normal as well as pathological aging continue to emerge. For example, observational evidence suggests that throughout adult life, there may be opportunities to protect and even enhance brain and cognitive function through prudent attention to modifying factors such as lifestyle, work and recreational choices, exercise, diet, health management and even by other means such as cognitive training. To date, the available scientific data offer promise, but few definitive conclusions. Clearly, much more research is needed in this area. The coming decade will probably see an aggressive and focused international research effort to identify proven means to prevent cognitive decline and strengthen cognitive functions in healthy aging adults as well as to treat evident dementia. A potential risk for the field of cognition and aging is that the growth of the largely unregulated commercial market for brain fitness products targeted to consumers will continue to out-pace the advancement of science that demonstrates the benefits of these approaches. This has been the unfortunate experience with the neutraceutical industry in which commercial interests have touted the cognition sparing benefits of herbal and other supplements and remedies in the absence of sound supporting scientific data.

However, with these cautions in mind, the opportunities for offering valid hope to protect our cognitive functions and strengthen our cognitive weaknesses as we age remains very promising as the understanding of neuroplasticity, brain reserve and cognitive reserve continues to evolve.

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Executive summary

Rationale behind brain exercise to avoid cognitive decline

- The population is aging across the globe at an unprecedented rate.
- The aging process is associated with a decline in certain cognitive functions in healthy elderly as well as an increased prevalence of more significant cognitive decline or dementia due to disorders such as Alzheimer's disease.
- Adults appear to retain the ability to maintain and improve cognitive function through mid and late life through the innate biological process of neuroplasticity.

Aging-related cognitive decline

- Normal aging is associated with changes in specific cognitive domains. Acquired information (vocabulary, knowledge and facts), often described as 'crystallized intelligence' is stable with age and may continue to improve over time.
- The more dynamic abilities to problem solve, recall new information, manipulate data, and to do so with speed, sometimes described as 'fluid intelligence', may decline in the normal aging process.
- A substantial number of older people will suffer pathological changes in cognition such as mild cognitive impairment and overt dementia, of which Alzheimer's disease and stroke are the most common causes.

Cognitive training strategies

- A limited number of rigorously designed and well-controlled cognitive training programs have demonstrated benefit in improving domain-specific cognitive functions in healthy elderly and mild cognitive impairment patients.
- Whether improvement in test performance as a result of domain-specific training is associated with significant improvement in day-to-day functioning in the activities of daily living remains nonconclusive and additional scientific study is required.

Brain fitness market

- Despite the need for more rigorous studies to validate the efficacy of structured cognitive training programs, a rapidly growing commercial market of 'brain fitness' products targeted to consumers has developed. These involve web-based programs, games, executive training sessions and other modalities.

Future perspective

- With an aging population across the globe, there will be growing interest in preserving brain and cognitive health through adulthood.
- More scientific studies will need to be conducted to examine what cognitively stimulating activities, lifestyle choices, nutritional practices and health factors most positively impact brain health as we age.
- Ultimately, we will think of 'brain fitness' in a similar fashion to how we now approach cardiovascular fitness. To maintain optimal cognitive function as one ages will likely require a combination of good health practices, a steady routine of cognitive and aerobic exercise, pursuing optimal nutrition and having active engagement in stimulating, novel and rewarding social and recreational activities.

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