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Enhancing cognitive capacities over the life-span

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Cognitive capacities refer to memory, thinking, reasoning, problem-solving, planning and processing speed and are also broadly described as aspects of human intelligence. Early psychologists used the term 'intelligence' to refer to what was viewed as a form of 'innate' cognitive ability that was thought to be relatively fixed throughout life and strongly genetically based. However, over the past 50 years, this collection of cognitive abilities has been viewed increasingly in a fluid and dynamic way, recognising that there are strong environmental and experiential influences on cognitive development, as well as genetic influences (Horn 1987).

In order to think about enhancing cognitive function over the life-course we must make the assumption that cognitive abilities and their development are not fully predetermined (Baltes 1993). Genetic research has shown that heritability of intelligence increases through adulthood from about 20 per cent in younger adults up to around 80 per cent in old age.

However, this applies to level of cognitive function in old age; the rate of cognitive decline does not seem heritable (Deary 2012). Moreover, studies on heritability have used traditional psychometric

tests of ability and have not examined more dynamic measures such as neuroplasticity. Variability within individuals may provide scope for improvement and optimising cognitive function (Ackerman 1987).

For several decades it has been recognised that different cognitive abilities appear to be vulnerable to different experiences and neurological conditions (Dixon 2011; Tucker-Drob 2009). Abilities such as reasoning, information processing speed and the higher-level planning and executive function appear to decline more with normal ageing and have been described as 'fluid' abilities or 'mechanic abilities' (Baltes 1987). Abilities involving the accumulation of knowledge and expertise appear to increase slowly through adulthood and are less vulnerable to ageing (Baltes 1987; Horn and Cattell 1967). These have been described as crystallised or pragmatic abilities.

At the societal level, the value of cognitive abilities can be viewed as a form of 'cognitive capital' that enriches a nation's capacity to be innovative and productive, and contributes significantly to wealth. Hence there are both individual- and society-level perspectives to consider in relation to optimising cognitive function.

Why should we aim for optimal cognitive function in an ageing society?

There are at least three important reasons for research into optimising cognitive development and cognitive health, and the translation of these research findings for public policy. First, as mentioned above, cognitive capital is a resource for society that enables productivity in both the paid and unpaid workforce (Beddington et al. 2008). Greater overall cognitive capital will lead to increased employment and economic benefits. Second, better cognitive function in earlier life reduces the risk of an individual developing cognitive impairment in later life, reduces the risk of dementia and is associated with greater longevity (Deary et al. 2004). Individuals with better cognitive function will take longer to decline to the point where they are impaired. Third, better cognitive function helps individuals age well (Starr et al. 2003). Cognitive function enables many aspects of everyday life, such as managing finances, planning travel, and managing medical conditions.

Hence, optimising cognitive function will improve quality of life for individuals and societies and reduce the economic burden of health-care provision as individuals are able to maintain self-integrity and self-care for longer.

Cognitive decline, cognitive impairment and dementia—a continuum

Importantly, with increasing life expectancy the integrity of the brain and cognition into very old age has become a new focus for research. There is a direct link between cognitive ageing and dementia, with researchers often seeing cognitive function, cognitive impairment and dementia on a continuum (Figure 1), whereas 20 years ago these were often viewed as distinct domains of research. There is much focus on dementia, and the public generally fear developing dementia (Kim et al. 2015; Zeng et al. 2015). However, it is less widely recognised that cognitive impairment that is not severe enough to meet criteria for dementia affects approximately 10 per cent of adults in their 60s (Anstey et al. 2013a) and 20 per cent of adults aged 70 and older, about three to four times the number of older adults who have dementia (Plassman et al. 2008). A large proportion of older adults with Mild Cognitive Impairment ultimately develop dementia (Farias et al. 2009) and hence Mild Cognitive Impairment is a strong risk factor for dementia.

Mild Cognitive Impairment impacts on quality of life and the capacity for independent living (Anstey et al. 2013b).

In our epidemiological study, the PATH Through Life, we found that adults aged in their 60s with Mild Cognitive Impairment reported higher rates of difficulties with instrumental activities of daily living such as reading maps, shopping, making telephone calls, and taking medications (Anstey 2013b). Hence, with an ageing population, it is crucial that we identify and implement methods to enable individuals to enhance their cognitive abilities and maintain them into very old age. Ideally, a minimal number of adults will experience cognitive impairment in their old age and few will develop dementia.

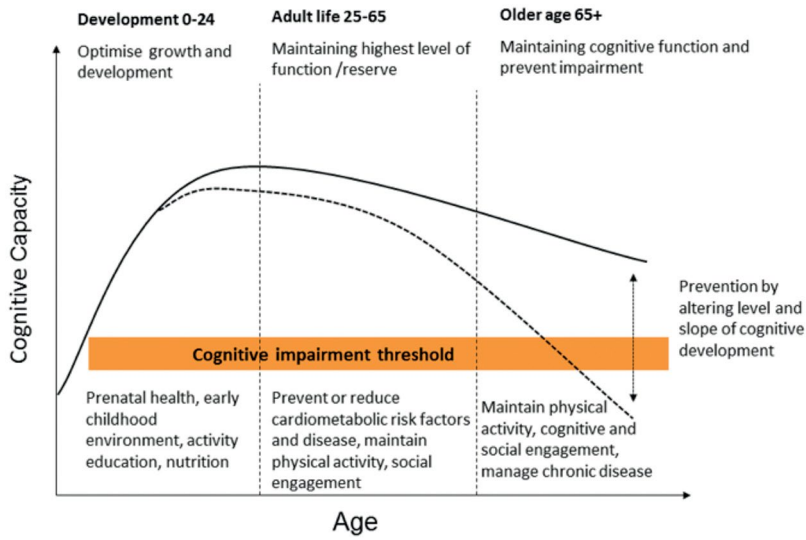

Figure 1. Schematic representation of the trajectory of cognitive development over the life-course

Capacity may vary according to lifestyle, environment, education and health.

Source: Provided by author.

Life-course perspective

When ageing research focuses exclusively on older adults, for example analysing data from studies of adults aged over 70 years, the contributions of earlier life are often overlooked. In the case of cognitive ageing, the starting point for an individual's cognitive development is prenatal, but the critical point for understanding their trajectory is the peak of cognitive ability reached in the mid-20s and then the rate of decline in cognitive abilities that commences in late-middle age. It is widely recognised that a life-course perspective needs to be taken into account for the development of cognitive abilities over the life-course (Baltes et al. 1999). Cognitive function in late life is influenced by the accumulation of the impacts of risk factors, insults to the brain, neuropathology, and cognitively enhancing activities that may provide some buffer against the impact of risk factors.

Figure 1 presents a schematic representation of cognitive development over the life-course, showing that cognitive impairment is on a continuum with normal age-related cognitive decline. The schematic illustrates the trajectory for cognitive growth, showing the peak in the mid-20s for fluid abilities, and the general stability of cognitive function in middle-age, followed by decline in late life. It is clear from this figure that increasing the peak of cognitive function in young adulthood will improve cognitive function for the remainder of the adult life-course. And hence, optimal cognitive ageing requires investment in early cognitive development (Anstey 2014). Similarly, maintaining cognitive function in middle-age will contribute to adults ageing well, minimising risk of cognitive impairment. The fact that cognitive function in late life is the accumulation of both cognitive growth in childhood and early adulthood, and the degree of maintenance through middle-age, means that a life-course approach needs to be taken to cognitive ageing at a public policy and health promotion level.

Taking a life-course approach to optimal cognitive ageing requires focusing different elements of the cognitive trajectories over the life-course and developing appropriate interventions for different ages or phases. Typically, cognitive function is stable in middle-age apart from the slowing of reaction time and processing speed. However, by the mid-60s, decline in cognitive function may start to occur. The age at which cognitive abilities start to decline and the rate of decline are influenced by a range of risk and protective factors. An example of how both level and slope of cognitive function may be associated with specific risk factors is shown in Figure 2. This depicts the adult life-course cognitive data from the PATH Through Life project for smokers and non-smokers. Smokers perform more poorly at each age, and, in the oldest cohort, are starting to show a faster rate of decline in processing speed than non-smokers.

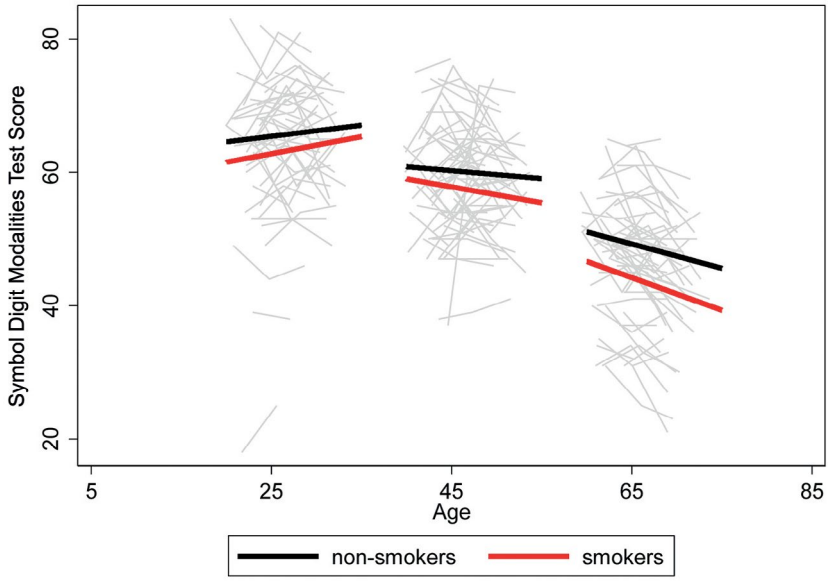

Figure 2. Processing speed ability for smokers and non-smokers aged in their 60s over eight years

Smokers show lower level and faster decline.

Source: Provided by author.

Cognitive reserve

The 'building of intelligence' in early life through enriched environments and education that promote peak functioning is related to another key concept described by psychologists as 'cognitive reserve' (Stern 2009). This 'reserve' provides individuals with a buffer to sustain their cognitive function when they develop neuropathology or experience diseases or stressors that impact on the brain and subsequent cognitive capacity. The idea of cognitive reserve was introduced originally to account for the finding at autopsy that some individuals who presented with Alzheimer's pathology did not have dementia. In a well-known study of 137 nursing home residents of whom 79 per cent were demented prior to death, 55 per cent had Alzheimer's pathology, 11 per cent had other neuropathology and 11 per cent had no neuropathology (Katzman et al. 1988). Of patients with dementia, 9 per cent had no neuropathology. This study demonstrated that there is no direct correlation between

neuropathology and dementia and such results have been replicated numerous times over the past two decades. Those without dementia, but who had neuropathology associated with Alzheimer's disease, had more neurones and intact pyramidal neurones and heavier brains than controls. It was therefore postulated that some individuals have a type of 'reserve' capacity, originally described as 'brain reserve' (Richards and Deary 2005; Stern 2002, 2006).

More recent research has used functional Magnetic Resonance Imaging (MRI) to explore the idea of brain and cognitive reserve (e.g. Stern et al. 2005; Stern et al. 2008). Greater activation of specific brain regions during a working memory task has been associated with higher levels of education (Sandry and Sumowski 2014; Sumowski et al. 2014). The idea of cognitive reserve developed from this research to explain the fact that individuals with higher levels of education and higher IQ appear to be at lower risk of dementia and more resilient to the impact of neuropathology on cognitive function. At present, we do not know the full potential of the human brain in terms of how much we can intervene to build cognitive reserve. It is likely that cognitive reserve can be enhanced by cognitive and physical training throughout adulthood.

Neuroplasticity

Neuroplasticity is related to cognitive reserve and is another key concept for understanding how we may optimise cognitive function (Petrosini et al. 2009; Whalley et al. 2004). Neuroplasticity refers to the capacity of cerebral neural pathways to grow and adapt to environmental exposures, behavioural changes, and specific cognitive and brain training (May 2011). This means that intellectually stimulating activities may maintain and even improve brain function during adulthood, potentially contributing to cognitive reserve and reducing the risk of dementia. Support for the benefit of a cognitively engaged lifestyle has been seen in studies linking lifestyle cognitive activity to the reduced risk of dementia (Fratiglioni et al. 2004). Results from the largest cognitive training study, the ACTIVE trial, have also shown benefits of an intervention that trained older adults in either memory, processing speed or reasoning skills as well as everyday function (Willis et al. 2006). Importantly, long-term

follow-up of participants trained on reasoning or processing speed showed cognitive benefits were maintained after 10 years (Rebok et al. 2014). Adults who participated in speed of processing training were also less likely to have given up driving over the follow-up period (Edwards et al. 2009).

In another cognitive training study, middle-aged and older adults used the speed of processing training paradigm from the ACTIVE trial and benefits were found for speed of processing training conducted both at home and by groups in a laboratory (Wolinsky et al. 2013). The benefits translated into between two and five years of prevented cognitive decline on standardised cognitive tests. Most cognitive training research has focused on older adults and children with attention deficit disorders; results typically demonstrate that cortical thickness can be increased through intensive repetitive cognitive exercises (Kueider et al. 2012). Research into music training has also demonstrated cognitive and brain benefits in children, but the long-term impact of musical training in childhood is not yet known (Lappe et al. 2011). Research in older adults has shown that there are brain changes associated with memory training (Engvig et al. 2010).

Brain training research in general has been criticised as improvements are only noted on those cognitive capacities focused on in the training; the transfer of benefit to everyday function has rarely been demonstrated. A number of empirical issues relating to dosage, frequency, intensity and type of training have not yet been resolved. Nevertheless, the field is part of a broader movement that will lead to discoveries about how to optimise cognitive function in ways that potentially will persist into late life.

Multidomain influences on cognitive development require a multidisciplinary approach—the CHELM Model

Influences on cognitive function draw from several different domains, including genetics, environment, sociodemographic factors, health behaviour, and disease (Fotuhi et al. 2012). Developments in education, neuroscience, medicine and psychology have each contributed to an emerging framework for understanding cognitive abilities over the life-

course. These also speak to potential areas where interventions may be conducted to reduce risk of cognitive decline, and even promote or improve cognitive abilities.

Interventions to address the influences on cognitive development may occur at multiple levels, from changing individual behaviour to changing public policy relating to education, health care or the environment (Fratiglioni and Qiu 2011). Ultimately, the better our society facilitates optimal cognitive development and maintenance, the better we will age as individuals and as a society (Beddington et al. 2008).

A framework for optimising cognitive function is required to pull together the multidomain nature of impacts on cognitive function that will ultimately lead to the level of cognitive ability an individual has in old age (Anstey 2014). I have previously proposed the Cognitive Health Environment Lifestyle Model to depict a framework for understanding influences on cognitive function that may guide policy and intervention.

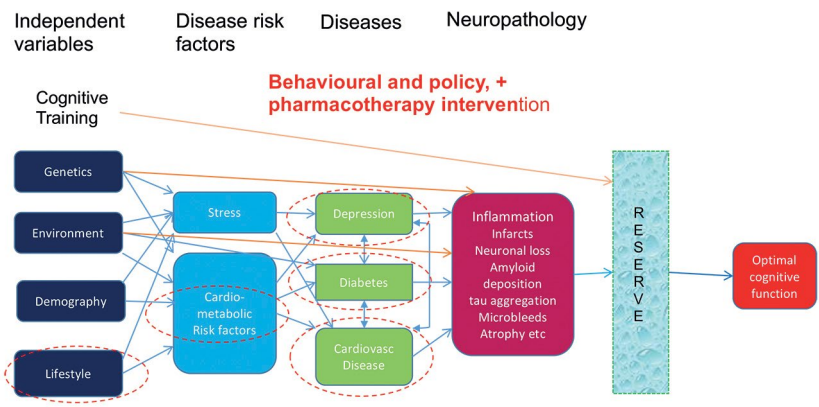

Figure 3. The Cognitive Health Environment and Life Course Model
Source: Adapted from Anstey (2014).

This model depicts how various domains influence cognitive outcomes, providing a framework for interventions at the levels of public policy, lifestyle and behavioural changes, and pharmacotherapy.

According to the CHELM framework, intervention can occur through public policy, non-pharmacological behaviour change interventions, pharmacological interventions and activities to develop cognitive

reserve. Public policy interventions are required to address environmental and contextual influences on cognitive development and cognitive function. These include ensuring as many children as possible receive high-quality education to develop brain structure and brain reserve. Retaining children in school and promoting lifelong learning and occupational training can be influenced by public policy in relation to the provision of education and the maintaining of standards of education.

Public policy is also important for addressing environmental influences such as air pollution in large cities, and the impact of the built environment on the lifestyle behaviours that ultimately impact on the brain and cognition. Environmental factors influencing cognition may, for example, include the design of environments, access to high-quality unprocessed food and access to sporting facilities that encourage individuals to engage in activities that promote health and wellbeing and ward off disease. Establishing building and design codes that take into account the health and capacities of communities and populations with specific needs will ultimately lead to gains in cognitive capital as well as reduced prevalence of chronic diseases. Hence, our society's approach to a broad range of issues and inequality can be viewed in terms of how such factors impact on the cognitive health of individuals, which in turn contribute to how well individuals will age.

Behavioural interventions are required to address risk factors for chronic disease that are also linked to brain and cognitive health. These include sedentary behaviour (Lautenschlager et al. 2010), diet quality (Ashby-Mitchell et al. 2015), smoking (Anstey et al. 2007) and unhealthy alcohol drinking (Anstey et al. 2009). While Body Mass Index (BMI) is not a health behaviour it is a medical condition that may be influenced by health behaviour as well as medical treatment. Both low BMI (underweight) and high BMI (overweight and obese) in middle-age have been linked to increased risk of Alzheimer's disease and dementia (Anstey et al. 2011).

Emerging research in the field of dementia risk reduction is focusing on developing ways of reducing behaviours that increase the risk of cognitive decline and dementia. For example, we have developed an online dementia risk-reduction intervention called Body Brain Life (BBL) (Anstey et al. 2013a). BBL includes seven modules, two of which educate individuals about dementia and dementia risk reduction. Another five modules address individual health behaviours

using behavioural change principles and techniques such as goal-setting and self-monitoring. Other more intensive interventions to improve cognitive decline have involved walking groups, personal exercise prescription and individual dietary prescription and support (Ngandu et al. 2015; Richard et al. 2012).

Preliminary results from one large European risk-reduction trial has shown that two years post-intervention, cognitive function was improved in the intervention group compared with a control group that received usual care (Ngandu et al. 2015). As depression is an established risk factor for dementia, behavioural interventions to reduce depression are also an avenue for dementia risk reduction. Protective behaviours that reduce risk of dementia include increasing social engagement (Fratiglioni et al. 2004), cognitive engagement (Wilson et al. 2002) and eating fish (Fotuhi et al. 2009).

Pharmaceutical interventions are also appropriate to treat conditions that increase the risk of dementia. These include hypertension, diabetes, heart disease and depression. Recent studies have identified cardiovascular risk factors in young adults influence cognitive ability (Aberg et al. 2009), and cardiovascular risk factors in middle-age influence dementia outcomes in late life (Kivipelto et al. 2001). Other medical conditions linked to cognitive function and decline include head injury and diabetes. However, research is now looking beyond purely medical and health explanations for individual differences in cognitive function.

Environmental factors are of increasing concern in the domain of public health in relation to respiratory function, and there is now evidence for air pollution being associated with poorer cognitive function and Alzheimer's pathology (Calderon-Garciduenas et al. 2012).

There is growing evidence that a range of pesticides and other chemicals are associated with cognitive deficits, yet this area of research is currently limited due to a lack of high-quality data (Zaganas et al. 2013). Environmental factors relating to diet may affect entire populations, in addition to historical effects such as major societal stressors and traumas.

Our society still traditionally views early life as the period during which individuals undertake their education and vocational training. However, research on brain development combined with increasing

longevity suggests that our perspective on education needs to change. Participation in education at various points during adulthood may have influences on the brain that we have not yet imagined. Bringing all our knowledge together and creating the best possible public policy for cognitive health is likely to promote genuine increases in the numbers of adults who age well, and reduce the prevalence of late life dementia.

Future directions

Research into factors that reduce cognitive capacity and methods of optimising cognitive capacity is relatively new and many fundamental questions remain unanswered. For example, little is known about how interventions at specific ages may influence longer-term cognitive outcomes, and whether this again differs by sex and genetic risk profile. We still do not know the optimal dosage of most interventions, or for how long they need to be administered. Often cohort studies are limited by the initial measures included in the study, by short follow-up periods or attrition. Intervention studies are typically limited by highly selected and unrepresentative samples, and short follow-up periods, with few interventions lasting as long as two years. In the context of cognitive function over the life-course it is possible that interventions may need to be administered for decades or even lifelong, to demonstrate their potential. Cognitive change in healthy adults is very slow and hence it is difficult to detect the effects of interventions with small samples and over short time-frames.

In addition to unanswered questions about interventions, there are also unanswered questions about the sub-populations in whom they may be trialled. We do not know which interventions may be effective in adults who already have some degree of cognitive impairment and the extent of neural plasticity possible in adults with dementia. Many of our hypotheses relating to optimising cognitive function are based on observational research that links risk and protective factors to better cognition. However, to date there has not been enough research to confirm whether risk modification will lead to reversibility of cognitive decline or improvement. With increasing longevity, it is unknown whether the same risk profiles associated with cognitive decline in say adults in their 80s will be associated with cognitive

decline in adults in their 90s or beyond 100. Some recent research has suggested that the increased longevity associated with lack of risk factors (e.g. non-smoking) may actually increase the time spent with cognitive impairment over the entire life-span because adults simply live longer and age is the greatest risk factors for cognitive decline (Anstey et al. 2014). Altogether, there is a need for a major research effort in enhancing cognitive capacities over the adult life-course that will have major benefits for individuals and societies.

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