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# Cognitive Ageing

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## Abstract

Cognitive decline is the first outward sign of dementia, which has a major public health impact on individuals and governments around the world. As individuals age, cognitive abilities gradually start to deteriorate for independent or combined genetic and environmental causes. Given that very little can be done regarding our genetic inheritance, the focus of the current research is on modifiable risk factors across the life course. There is a well-established relationship between specific lifestyle behaviours and cognitive decline, but extremely limited research on the role of combined lifestyle factors. This chapter aims to describe the process of cognitive ageing on multiple cognitive domains (fluid and crystallised), highlighting the changes in cognitive performance occurring as a normal process of ageing, as well as the most severe forms of cognitive impairment indicative of probable risk of dementia. Also, the role of modifiable risk factors such as lifestyle behaviours (alcohol, smoking, physical activity and dietary patterns) will be evaluated in relation to healthy cognitive ageing and preventions of cognitive decline. There are many questions to be answered regarding the biological foundations of cognitive ageing across the spectrum, and the potential role of lifestyle behaviours in reverting the accelerated changes in the cognitive ageing process.

**Keywords:** cognition, dementia, lifestyle, fluid intelligence, crystallised

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## 1. Introduction

Optimal physical and mental health represents a prerequisite to an optimal quality of life. Highly complex mental capabilities such as memory, processing speed, attention, orientation language, reasoning and problem-solving are vital to everyday functioning and activities of daily living. However, these abilities tend to decline as part of normal ageing [1]. The rate of cognitive decline varies considerably depending on genetic influence [2–4], early environment

[5, 6], education [7] and social class in adulthood. A significant decline in cognitive functioning has also been attributed to lifestyle behaviours such as alcohol consumption [8], fruit and vegetables intake [9], cigarette smoking [10] and low exercise (both physical and mental training) [11, 12]. A serious degree of cognitive decline is not inevitable, but remains one of the greatest concerns in the current climate of our ageing populations around the world, given that cognitive impairment and serious levels of cognitive decline represent important predictors for the development of dementia [13, 14]. Developing realistic strategies and interventions to reduce cognitive decline and prevent dementia should be considered a high priority by governments around the world [15].

## 2. Cognitive ageing

An optimal cognitive function is fundamental to independence, productivity, and quality of life, while the progressive debilitation in cognitive capability associated with cognitive impairment and dementia, makes these conditions the most feared scenarios for approaching the older age. Human brains seem to be under continuous modifications, which are dependent of cardiovascular health, lifestyle or injuries throughout life. Some changes are part of the normal process of ageing, while others are more severe and debilitating with an underlying neuropathology process.

There is no clear consensus in defining healthy or successful cognitive ageing, but it can be described as the maintenance of most cognitive abilities as until older age and a minimum variation in the spectrum of normal cognitive decline with ageing. There is an immense explanatory gap in understanding the biological foundations of cognitive ageing across the whole spectrum or what determines a slowed information processing and multitasking. Moreover, not enough is known about the mechanisms underlying different types of neuropathological changes, and whether individual choices of lifestyle behaviours can enhance these mental capabilities or slow the cognitive ageing process. A recurrent question in cognitive is whether the decrease in cognitive performance is related to healthy or pathological ageing processes. Building upon this, it is also important to understand the critical periods of life when the transition from healthy to pathological ageing does occur [16–19].

Ageing affects cognitive functions, primarily those associated with executive processing and other functions of the frontal lobe. Age-related changes in memory and other cognitive abilities occur at different rates (for example, reasoning skills, visuospatial facility and verbal memory decline more rapidly over the life course, while vocabulary, attention and calculation are more resistant to ageing). Learning, mental processing and visuomotor functions, such as visuomotor coordination, increasingly decline with age [20–23], suggesting that changes in specific skills are nested in a more global trend of decline which varies according to various cognitive functions. However, there is also evidence that the adult brain shows neuroplasticity and neurogenesis [24–26].

A distinction between two categories of cognitive capabilities has been proposed by Raymond Cattell [27] and further developed by John Horn [28]. They proposed a clear distinction between all types of cognitive capabilities in fluid and crystallised intelligence. Fluid cognitive ability is

considered a measure of cognitive capability involved in processing novel information (e.g. working memory and problem solving) efficiently and with increased flexibility. These aspects of cognition are particularly susceptible to ageing [29], see **Figure 1** adapted from [30]. The absolute level of fluid intelligence measured at any point in later life depends both on genetic inheritance, education, the peak level of cognition achieved across life and the rate of decline experienced by that age [30]. On the other hand, crystallised cognitive functions, which rely on over-learned cognitive skills and abilities or accumulated knowledge, remain preserved or even improve during ageing process [31], except for the advanced stages of cognitive impairment or dementia [32].

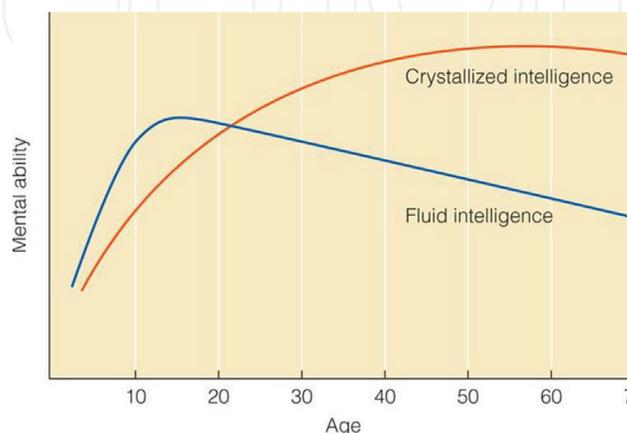
The subtle decline in fluid cognitive abilities has been thought to begin as early as age 50 [6, 33, 34] and includes subtle deterioration of fluid cognitive abilities such as memory [35], verbal fluency [36, 37], visuospatial and constructional ability [38], attention, speed and concentration [35]. Previous evidence highlighted that cognitive speed decreases by around 20% at age 40 and by 40–60% at age 80 [39, 40].

An important methodological challenge is to understand the diversity and typology of cognitive decline, the time of onset of decline, and the causes of this change.

The next sections will focus on two aspects of cognitive functioning (memory and psychomotor speed) that are particularly sensitive to ageing.

## 2.1. Memory

The term memory has been used broadly to refer to mental operations that involve encoding, retention and retrieval of information. Memory functions can be classified based on their temporal scale (short-term versus long-term) and the type of memory function (e.g. declarative versus non-declarative, episodic versus semantic) [41, 42]. Some of these aspects are more vulnerable to the effects of ageing than others. For example, Nilsson investigated episodic, semantic and short-term memory, priming, and procedural memory across the lifespan in a large longitudinal study and found a steady age-related decline in episodic memory as measured by free recall, cued recall, source recall, recognition and prospective memory tasks [43]. There was an increase in semantic memory capacity up to age 55–60, and



**Figure 1.** Schematic representation of fluid and crystallised intelligence over the lifespan adapted from [30].

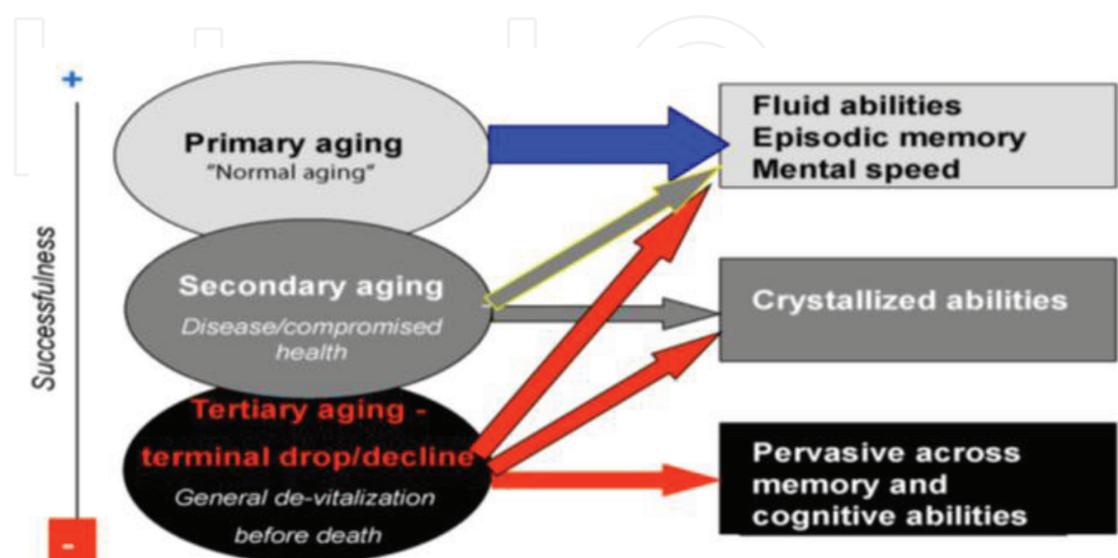
a significant decrease after that. The other types of memory remained unchanged. Episodic memory refers to remembering past experiences, places or times [44], and has been a central focus of research in cognitive ageing.

## 2.2. Speed of processing

Slower mental processing has often been identified as an underlying factor behind other cognitive deficit such as attention disorders [18, 45]. Methods for assessing mental processing speed are typically either computer-aided reaction-time tasks or paper-and-pencil tests that may to some extent also require psychomotor functioning. Tasks such as the Stroop test (word reading and colour naming) [46] and Trail Making are regarded as general (multidimensional) speed tests that also include the rates of reading, naming, perceptual and visual-motor functions. Stroop task is designed to measure cognitive control and assess the ease with which a person can maintain a goal in mind while suppressing a habitual response in favour of a less familiar one. Trail making measures attention, speed and mental flexibility. Mental speed is considered highly vulnerable to the effects of ageing process. A central hypothesis is that increased age is related to the deterioration of the psychomotor speed, utilised in many cognitive operations [19].

## 3. The cascade model of cognitive ageing

A life course approach to cognitive ageing and cognitive function was also emphasised by the cascade model of cognitive ageing proposed by Birren and Cunningham [47] (see **Figure 2**). While it is common to conceptualise the chronology of cognitive ageing from birth to later life, the cascade model suggests that it may be more informative to consider a framework of successful cognitive ageing in relation to the time to death rather than a follow-up from the time of birth.



**Figure 2.** The Cascade model of cognitive ageing, adapted from Birren and Cunningham [47].

The model describes primary ageing as a slow decline in mental progressing, often characterised by difficulties in memory (especially with new learning and retention), information processing, language and other aspects of cognitive functions. Secondary ageing represents a more rapid form of deterioration due to a pathological process such as dementia, and refers to a loss of fluid and crystallised cognitive abilities, while tertiary ageing raises the more complex issue of impairments in cognitive performance arising from overall biological devitalisation of the organism before the end of life. Many older individuals demonstrate no apparent cognitive impairment, while others, perhaps most of the aged population, suffer various degrees of cognitive change.

Another model proposed by Brayne and colleagues, describes the general trend of cognitive decline as a continuum, from “successful” and “normal” ageing to “mild cognitive impairment” and “dementia” [48]. This model presents a general trend of deterioration in all aspects of cognitive abilities, irrelevant of the competing risk of the potential neuropathological changes such as dementia. The authors considered that the “differences in behaviour were associated with environmental causes, genetic causes and individual decision-making processes” (p. 12–13). Despite several conceptualisations of mental ageing across the life course have been developed, it is important to link these models of mental decline to a multidirectional approach that searches for gains and losses across the life course [49].

#### **4. Cognitive performance and the ageing process**

Although age-related decline in cognitive performance is undeniable, there are two important caveats to this statement. First, most cognitive deficits that have been observed in non-demented older adults are typically limited to certain types of cognitive tasks. In particular, deficits have usually been seen on tasks that required problem-solving [50, 51], speed response on information processing [52], relied on executive processing [53], assessed a variety of types of memory [54], or assessed the acquisition and retention of novel skills [55]. The variability in cognitive decline that occurs with age has provided insights into the areas of the brain that are implicated in ageing, and this can help identify potential mediators of the relationship. Non-demented older adults are typically able to maintain their long-term memory and the ability to perform tasks that are considered to be less effortful regarding attentional demands [56, 57].

The second caveat regarding age-related declines in cognition is that there has been shown to be substantial variability in the rate of decline with age, and, that this process is extremely heterogeneous given that some older adults never experienced declines in their mental abilities. This achievement could be considered successful cognitive ageing, which has also been described as the evasion of disease and disability, continued engagement in social and productive activities, and sustained cognitive and physical functioning [58, 59]. The question why some people are affected more by ageing process than others remains unclear to date, but it is likely that there are certain genetic variants and clinical conditions that could potentially increase the risk of cognitive impairment. Over the past decade, several risk factors such as the e4 allele of the Apolipoprotein E gene, CVD, stroke, hypertension, diabetes, the metabolic syndrome, hypercholesterolemia, arterial fibrillation, smoking and atherosclerosis have been identified as predictive of increased cognitive decline and a higher risk of dementia [60–66].

Given the increase in the size of the population of older adults and the personal and social consequences of age-related cognitive decline, research related to the maintenance of cognitive functioning is of increasing relevance. From an environmental perspective, promoting healthy adult lifestyle behaviours may attenuate harmful effects of less modifiable risk factors. Therefore, identifying genetic and lifestyle factors which predict successful ageing represents an important direction for researchers in delineating the risk factors for cognitive decline and developing behavioural interventions designed to attenuate cognitive decline.

## 5. The role of lifestyle behaviours on cognitive ageing

Lifestyle behaviours refer to routine activities (e.g. smoking, alcohol, diet and physical activity) that could influence our health. Because of their impact on various health outcomes, the term “lifestyle behaviours” has also been referred to as “health-related behaviours”. Many studies have shown that lifestyle behaviours are associated with type 2 diabetes [67, 68], coronary heart disease [69] and mortality [70]. An example is a recent study that followed a cohort of more than 20,000 people aged 45 to 79 living in the Norfolk area in the United Kingdom between 1993 and 1997, which investigated the association between lifestyle behaviours and mortality [71]. The results of this study showed that people who smoked, drank more than 14 units of alcohol per week, consumed fewer than five servings of fruit and vegetables per day, and were inactive, had a four-times higher mortality risk than those who exhibited none of these lifestyle behaviours. An important aspect that needs further highlighting is that lifestyle behaviours are not always independent of one another, and may also have additive effects on various health outcomes.

Optimal control and management of lifestyle factors demonstrate efficacy in the prevention of cognitive decline and dementia [72–75], highlighting an intertwined link between the risk factors for cardiovascular and cerebrovascular disease and dementia. Accumulating evidence points to the potential risk factors of cardiovascular disorders (e.g. midlife obesity and cigarette smoking) and the potential protective roles of psychosocial and lifestyle factors (e.g. higher education, regular exercise, healthy diet, intellectually challenging leisure activities, and an active socially integrated lifestyle).

Factors showing a considerable influence on decreasing the risk of dementia and cognitive decline are social and cognitive engagement. Other influences such as physical activity, which increases cerebral blood flow and in turn promotes nerve cell growth and enhanced cerebrovascular function, seem to be the most frequently cited lifestyle in the cognitive ageing literature. However, it is highly probable that physical activity may also enhance cognition through other mediator factors such as depression, sleep, appetite (diet), and energy levels by postponing or preventing age-related diseases (e.g. diabetes, hypertension) known to affect cognition. Furthermore, there were also well-known documented benefits of non-smoking [76–78], moderate alcohol consumption [8, 79–82] and healthy dietary choices [78, 83–85] for a healthy and successful cognitive functioning from mid to later life.

In addition to considerable observational data of the independent effects of lifestyle factors, there is now increasing empirical evidence from intervention studies [73], that alterations in

lifestyle factors may lessen an individual's risk of developing cognitive decline. The evidence of a correlation was strongest in the case of an increase in an individual's level of physical activity, followed by cessation of smoking. These interventions carry few risks and have many additional health benefits, so can be recommended for most of the older population. Other factors such as increasing social engagement, cognitive stimulation and homocysteine-lowering vitamin supplements also appear promising, with considerable observational evidence supporting their uptake, although there is still a lack of empirical evidence for these interventions [73]. Similarly, fitness training interventions were found to have robust but selective benefits for cognition, with the largest fitness-induced benefits occurring for executive-control processes [86]. This indicates that cognitive and neural plasticity could be maintained throughout the lifespan. However, the real risk of dementia is probably underestimated, and it is not clear how many people quit smoking between the time of the initial survey and the onset of dementia, but there were clear long-term consequences of mid-life smoking.

Research has also shown that diet can help prevent, better manage or even reverse conditions such as hypertension, hyperlipidemia (high cholesterol), hyperglycemia (high blood sugar) and atherosclerosis that may lead to cardiovascular and cerebrovascular disease. In turn, this affects optimal functioning of organs including the brain due to inefficient transfer of glucose and oxygen necessary for optimal neuronal transfer, with a significant impact on cognitive functioning.

To current date, only limited work has investigated the combined effect of these behaviours in relation to cognitive outcomes, and when this evidence exists, findings are inconsistent. For example, a French study investigating alcohol (wine consumption) and smoking in 833 older adults from the Eugeiria longitudinal study of cognitive ageing showed that there was no apparent protection from these combined behaviours against Alzheimer's disease. For instance, smoking was associated with an increased decline in language performance even when adjusted for wine consumption, and the latter was associated with an increased decline in attention and memory while adjusting for smoking [87]. The study cites previous evidence, however, suggesting that only smoking (using a pack-years measure) was significantly related to declining in digit span, while low-to-moderate alcohol consumption was not significantly associated to a subsequent three-year change in performance.

More recent work has highlighted that the number, duration, and the interaction between some unhealthy behaviours were all associated with subsequent cognition in later life. In a study of London civil servants (Whitehall II cohort) the interaction between alcohol and smoking was investigated, and these results highlighted that the combined effects of smoking and alcohol consumption were greater than the individual effects. Participants who were smokers and drank heavily experienced a 36% faster cognitive decline compared to non-smokers who drank in moderation. These associations were maintained after adjusting for age, sex, education and chronic diseases [88].

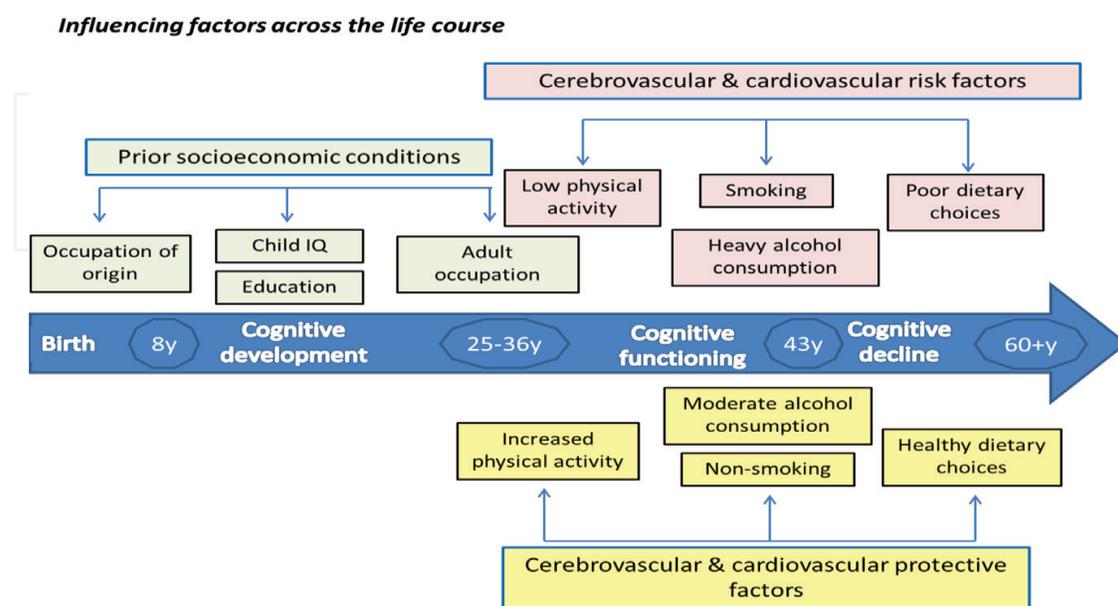
A previous investigation conducted in the same cohort highlighted that participants with three to four unhealthy behaviours were more likely to have poor executive function and memory, compared to those with no unhealthy behaviours. Also, the odds of lower cognitive function were higher when the number of unhealthy behaviours was repeated over time (across three different waves) [89]. Similar findings from the Suwon Longitudinal Ageing Study (SLAS) showed that a combination of multiple positive lifestyle behaviours (such as non-smoking,

vegetable consumption and social activity) was associated with the higher cognitive ability [90]. However, since these behaviours tend to cluster [91, 92], the extent to which apparent effects of one behaviour were attributable to (i.e. confounded by) another is uncertain.

Furthermore, relatively little is known about the longitudinal effects of these behaviours on the cognitive decline; yet associations among multiple lifestyle behaviours emphasise longitudinal studies since patterns of behaviours tend to develop over decades, with implications for targeted interventions to change the aggregate public health risk [93]. The life course approach to age-related diseases [94, 95] provides an important opportunity to identify the nature and timing of different environmental contributions to neuronal damage and the risk of dementia across life [96].

Risk and protective factors for health can exert their most critical influences at different ages [97]. This was acknowledged by the life course approach and the hypothesis that positive lifestyle behaviours such as non-smoking, being physically active and choosing healthier diets may protect cognitive functioning and a slow cognitive decline in later life. Fratiglioni et al. identified key periods for potential risk and protective factors [97]. Early life seems to be most critical for the development of cognitive reserve (learning and education) [98–100] when distal adverse influences (such as poor childhood social circumstances) contribute to the risk of adult disease or later life risk of dementia. Lifestyle behaviours, including those that influence cardiovascular and metabolic risk, become more influential in midlife, although some, such as diet and physical activity, track back into childhood [101, 102], whereas mental and physical activity patterns may continue to moderate these risks into later life [103, 104] (see **Figure 3**).

Cadar et al. examined the associations between lifestyle behaviours in early midlife (36 and 43 years) independently of each other, and in combination, in relation to cognitive performance at age 43, and cognitive decline over 20 years from 43 to 60–64 using the Medical Research Council 1946 British Birth Cohort [78]. Key findings for the former analyses were



**Figure 3.** A life course timeline presenting the risk and protective factors across the life course.

that the highest level of midlife physical activity was associated with better memory (but not search speed) at baseline, and a consistently healthy dietary choice was associated with slower memory decline from mid to later life. In addition, the highest level of physical activity at age 43 and across early midlife was associated with slower visual search speed decline, independently of every other lifestyle behaviour and of selected covariates: social class of origin, childhood cognition, educational attainment, adult social class, symptoms of anxiety and depression, and clinical conditions (hypertension, diabetes, cancer, CVD) and frailty. Smoking was not associated with either cognitive outcome, but since the number of heavy smokers was relatively low in this sample, these conclusions should be interpreted with caution. It should also be noted that their findings for dietary choice and physical activity were not always consistent at different ages across midlife, compared to effects of the cumulative scores.

The associations between physical activity and a slower decline in visual search speed in Cadar's study, and between healthy dietary choice and memory, are new findings and were not previously tested on this cohort. In the former case, physical activity was not investigated in relation to search speed in the previous study; in the latter case, midlife cognition has not previously been studied in relation to diet on this cohort. On the other hand, the associations between heavy smoking at age 43 and faster memory decline previously reported between ages 43 and 53 (Richards et al., 2003) were not replicated here with the 20-year period of cognitive change from 43 to 60+ years. The loss of the cumulative midlife heavy smoking-memory decline association may be due to low statistical power resulting from the relatively high odds of morbidity and premature mortality in this sub-group (135 study members smoking more than 20 cigarettes per day at age 43 were represented in the previous study, compared to 22 in the present study).

Evidence from a study of London civil servants found an effect of sex on the association between smoking and cognitive decline in a study of London civil servants. Their results showed that men who smoked showed faster decline than non-smoking men over a 10-year period, after adjusting for the effects of heart disease, stroke and lung function on mental abilities, while for women there were no differences in cognitive scores over the same period. This could be related to the lower number of female participants as compared to males in the Whitehall II study [105]. In relation to physical activity, leisure-time physical activity at least twice a week in midlife was associated with reduced risk of memory decline in the Cardiovascular risk factors, Ageing and Incidence of Dementia (CAIDE) study, after adjustment for age, sex, education, follow-up time, locomotor disorders, APOE genotype, vascular disorders, smoking, and alcohol consumption [106]. Similarly, in The Mayo Clinic Study of Ageing moderate exercise in midlife or late life was associated with reduced odds of Mild Cognitive Impairment (MCI) [107]. In contrast, results from the Chicago Health and Ageing Project reported that physical activity conducted within 2 weeks of the date of baseline cognitive assessment was not associated with risk of cognitive decline in an older population [108].

Given that lifestyle behaviours are modifiable risk factors indicates that encouraging a healthy lifestyle may prevent or ameliorate cognitive decline and underlying cerebrovascular and cardiovascular risk factors [109]. Designing interventions that promote healthy lifestyles should represent key components of any response to the potentially overwhelming problem of dementia prevention.

## 6. Policy implications

Despite major progress in understanding the neurobiology of cognitive impairment and dementia, there are still no clear determinants and complete causal models available for explaining risks for this condition [110]. As noted, the Department of Health National Dementia Strategy acknowledges that “what is good for the heart is also good for the brain”. This implies that limited consumption of alcohol, non-smoking, an active physical lifestyle, and a balanced, low-energy-dense/nutrient-rich diet should all contribute to a healthy brain. Cognitive decline itself is a predictor of dementia. Thus, the implied message is that by changing lifestyle behaviours dementia may be delayed or even prevented.

## 7. Conclusions

This chapter has presented an overview of the process of cognitive ageing from a life course perspective and discussed the role of lifestyle behaviours on successful cognitive ageing. The evidence presented highlights the important role of lifestyle behaviours (especially physical activity and healthy dietary choices) on maintaining an optimal level in different aspects of cognitive function. Adopting more than one healthy lifestyle behaviour across early midlife seems to be protective against a faster decline in several domains of cognitive functioning, highlighting a dose response with the number of lifestyle behaviours adopted. With an increase in the ageing population, the number of older people affected by cognitive decline and dementia is continually rising, causing a major public health burden on individuals and governments around the world.

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## Conflict of interest

The author declares no financial relationships with any organisations that might have an interest in the submitted work; no other relationships or activities that could appear to have influenced the proposed work.

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