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The EAT–Lancet reference diet and cognitive function across the life course

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The EAT–Lancet Commission devised a sustainable reference diet with the aim of reducing the incidence of non-communicable diseases and mortality globally while improving food system sustainability. The extent to which the reference diet supports cognitive function across the life course, however, has not yet been evaluated. This Review assesses the evidence for diet supporting cognitive function from childhood into old age. A comprehensive but non-exhaustive literature search was done, synthesising studies that investigated the effect of whole foods on cognition in healthy, community-dwelling human participants. We found that the current evidence base is weak with mixed conclusions and multiple methodological caveats, which precludes strong conclusions pertaining to the suitability of dietary recommendations for each food group per age group. Long-term intervention and prospective cohort studies are needed to reduce this knowledge deficit. Revising dietary recommendations with the aim of maintaining an adequate nutrient intake to sustain healthy cognitive function across the life course could be worthwhile. This Review outlines recommendations for future work to help improve the current knowledge deficit regarding dietary intake and cognitive function across the life course and its implications for dietary guidelines such as the EAT–Lancet Commission.

Introduction

In January, 2019, the EAT–Lancet Commission described a universal, healthy reference diet to realign global food systems, improve environmental sustainability, and nurture human health.¹ The reference diet is based on global scientific targets, derived from the best available evidence for healthy diets and sustainable food production, and allows the global food system to operate within safe boundaries to help achieve the UN Sustainable Development Goals and the Paris Agreement. The diet is largely plant-based, consisting of whole grains, fruits, vegetables, nuts, legumes, unsaturated oils, low to moderate amounts of seafood and poultry, and no or low red meat, processed meat, added sugar, refined grains, and starchy vegetables. For most people, the reference diet requires a substantial dietary shift. Specifically, it requires a global increase of more than 100% in consumption of healthy foods and a more than 50% reduction in consumption of foods that are not as healthy as other foods. The Commission acknowledges the need to implement these changes differently depending on the region, and proposed that shifting from current unhealthy dietary patterns to the EAT–Lancet reference diet could prevent 10·8–11·6 million (19·0–23·6%) deaths per year globally by reducing the incidence of diet-related obesity and non-communicable diseases, such as cardiovascular disease, cancer, and diabetes.¹

The Commission proposed that a healthy diet should not only promote the absence of disease, but also optimise physical, mental, and social wellbeing.¹ Optimal cognitive function, broadly defined as the ability to learn, remember, and deploy attention, is essential to mental wellbeing and functioning in daily life. In typical conditions, a slow process of neural atrophy that affects cognitive function begins around 30 years of age.² Furthermore, increased cognitive decline has been prospectively associated with increased risk of death.³

The trajectory of cognitive decline is established by a complex interplay of genetic and environmental factors, including early life exposure to cognitive activities, socioeconomic status, and education. Nutrition has attracted substantial attention as a modifiable environmental factor due to its potential ability to reduce the risk of age-related cognitive pathologies through the myriad of nutrients and food ingredients that might benefit cognitive function.⁴

The creation of the reference diet relied on available evidence pertaining to non-communicable diseases, focusing mainly on cardiometabolic health, cancer risk, and mortality. In this Review, we provide a non-exhaustive narrative overview of the current evidence base to further evaluate whether the EAT–Lancet reference diet is appropriate for maintaining healthy cognitive function across the life course. A major challenge in establishing dietary strategies to improve human health is that nutritional requirements and the effect of dietary modification on cognitive function can vary throughout different life stages.⁵ Therefore, we assessed available evidence across the life course (from children aged 2 years to older adults) and restricted our analysis to healthy community-dwelling individuals to match the approach of the Commission.¹

Whole grains

Whole grain consumption during childhood and adolescence seems to variably affect different cognitive domains. In a longitudinal study in young children, diet scores indicated that whole grain consumption was not associated with cognitive outcomes at age 10 years.⁶ However, consumption of 360 g per day of a mixed-grain product during a 9-week period protected against the effects of mental fatigue induction on attention, vigilance, and response impulsivity in adolescents.⁷ Mixed-grain products could also mitigate the adverse effects of white

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rice on attention and impulsivity.⁸ Other cognitive domains, such as visual perception and visuospatial reasoning, are improved when children consume more than 46 g per day of high-fibre grain products.⁹ There are no studies on the effects of whole grain consumption on cognition in adults.

The relationship between whole grains and cognitive function in older populations is weak. Consumption of rye bread during a 3-day period showed no significant effects on cognitive performance compared with consumption of white wheat-based bread. However, cardiometabolic health markers, such as postprandial insulin response and glucose tolerance, were improved after rye bread consumption and were correlated with improved working memory and selective attention.¹⁰ Improved cardiometabolic health has a positive effect on cognitive function,^{11,12} suggesting that cognitive performance in older adults could be maintained by whole grain consumption. Furthermore, a positive correlation was found in women older than 60 years, in whom intake of whole grain cereal was associated with improved cognitive function assessed by the Mini Mental State Examination (MMSE)—a measure of global cognitive function and a screening tool for cognitive impairment, executive function, memory, and attention.¹³

Tubers or starchy vegetables

There are few studies of the effects of tubers and starchy vegetables on cognitive function. Improved verbal declarative memory was found in children after consumption of 50 g of deep-fried potatoes compared with consumption of 50 g of mashed potatoes and 50 g of white rice.¹⁴ Older adults with poorer memory at baseline showed improvement in verbal declarative memory independent of plasma glucose concentration after consumption of carbohydrate sources compared with control individuals.¹⁵ However, as this evidence is from studies with small samples sizes, it should be interpreted with caution.

Fruits and vegetables

In a 2018 meta-analysis of observational studies, increased fruit and vegetable intake was associated with reduced risk of cognitive impairment.¹⁶ However, evidence associating fruit and vegetable intake with cognitive health across the life course has variable findings. In children and adolescents, a systematic review showed that consumption of healthy foods (including fruits and vegetables) was positively associated with executive function, whereas consumption of unhealthy snack foods had a negative effect on executive function.¹⁷ Fruits and vegetables might not have the same effect on each cognitive domain. In a prospective cohort study of adults done over 13 years, intake of fruits and vegetables, fruits alone, and fruits with high vitamin C and vegetables were positively associated with verbal memory. However, intake of fruit and vegetables, vegetables alone, and of

fruits and vegetables with high β -carotene were negatively correlated with executive function.¹⁸

The beneficial effect of fruit and vegetable consumption on cognitive health is more evident in older adults. Older participants showed low error rates on a verbal learning test after 90 days of consuming 12 g of freeze-dried blueberry, blended into a powder compared with placebo.¹⁹ Similarly, high consumption of fruits and vegetables has been associated with a 26% reduction in risk of cognitive disorders.²⁰ Furthermore, differences in cognitive function equivalent to 3·5 years of age between the lowest and highest quintile of total vegetable consumption have been reported, with individuals in the lowest quintile being twice as likely to show cognitive decline than individuals in the highest quintile.²¹

Compared with fruit, consumption of vegetables could be more beneficial in old age. The Chicago Health and Aging Project (CHAP)²² cohort showed no association between combined fruit and vegetable intake and cognitive change during a period of 6 years. However, high vegetable intake alone was significantly associated with slow cognitive decline, with a further 35% reduction in the annual rate of cognitive decline in the fourth quintile of vegetable consumption versus the first. Individuals who consumed two or more servings of vegetables per day exhibited the equivalent cognitive age of individuals who were 5 years younger.²³ Green leafy vegetables had the strongest association with cognitive function, which was also shown in a separate population in which individuals consuming one or two servings of green leafy vegetables per day had cognitive performance equivalent to being 11 years younger than individuals who rarely or never consumed them.²⁴ Based on the current evidence, fruits and vegetables, although generally beneficial for cognitive functioning, could have differential effects on specific cognitive domains across the life course; these differential effects require further investigation.

Dairy foods

Studies on the effects of dairy food consumption on cognitive function in individuals at a young age are scarce. One study reported an association between dairy consumption at a young age and better cognitive outcomes at age 10 years.⁶ In addition, consumption of a high dairy diet during a 12-week period improved scores on spatial working memory compared with a low dairy diet in adults who were overweight or obese (BMI ≥ 25).²⁵ Similarly, daily consumption of dairy products was positively associated with various cognitive functions and positively associated with the outcomes of the MMSE compared with individuals who never or rarely consumed dairy foods.²⁶ However, having more than one glass of milk a day between the ages of 45 years and 64 years was associated with a 10% decline in global cognitive functioning and memory 20 years later.²⁷ The type of dairy product or the fat content of the dairy product could

affect this relationship, and sex differences might also be present. For example, total dairy food consumption, specifically cheese, was positively associated with information processing speed and global cognitive performance.²⁸ Similarly, high intake of low-fat yogurt was positively associated with memory recall in men, whereas whole-fat dairy consumption (eg, ice cream and cream) was associated with cognitive deficits.²⁵

Regarding older adults, combined prospective analysis of the Supplementation en Vitamines et Minéraux Antioxydants (SU.VI.MAX)²⁹ cohorts showed that total dairy product consumption was not associated with cognitive function, but milk intake was negatively associated with verbal memory performance. Moreover, women who consumed more than the daily recommended amount of dairy showed worse working memory performance.³⁰ By contrast, other studies indicate that dairy consumption could be beneficial for older adults. Increased frequency of cheese intake has been associated with decreased cognitive impairment.³¹ The Maine-Syracuse Longitudinal Study²⁶ revealed that the individuals who consumed the highest amounts of dairy products had the best cognitive performance on global cognition, visuospatial memory, and executive function compared with individuals who rarely consumed dairy foods. From the scarce and inconclusive available evidence, the effects of dairy consumption on cognitive performance could be dependent on dose, type, and fat content. Further investigation of the effects of this food group is required.

Sources of protein

Meat

Meat intake in the EAT–Lancet reference diet is divided into three categories: beef and lamb, pork, and chicken and other poultry. The reference diet advocates a reduced meat intake, but specifies a recommended intake of three times as much chicken and other poultry than red meats.

A systematic review of children and young adults showed sparse evidence for the effects of beef consumption on cognitive function because of a small number of studies, heterogeneous study designs, and diverse study populations.³² Similarly, a systematic review of adults published in 2020 found no association between total meat intake and cognitive function or cognitive disorders.³³ However, a sub-meta-analysis showed a reduced likelihood of cognitive disorders in individuals consuming meat once a week or more.³³ Furthermore, a large cohort study, comprising almost 500 000 participants, showed that each additional portion per week of red meat intake was associated with reduced cognitive function, such as reduced fluid intelligence and memory performance.³⁴ Some of these associations only occurred in men, such as those pertaining to reaction time, fluid intelligence, and prospective memory. There might be a protective effect of increased red meat intake in both men and women on visuospatial memory.

The evidence base in older adults is small. In a 2020 study, exercise-induced improvements in age-associated cognitive function did not differ between exercise in combination with consumption of either 80 g of cooked lean red meat or 80 g of carbohydrates. Both intervention groups showed improvements in global cognitive function and executive function.³⁵ Meat consumption was not shown to have more of a detrimental or beneficial effect than in the carbohydrate-consuming group. However, a 13-year follow-up of older adult women showed an increased likelihood of cognitive decline in women who consumed low quantities of poultry and animal fats. These women also had an increased likelihood of consuming high intakes of pastries and cakes, which could contribute to the observed cognitive decline.³⁶ Compared with the lowest intake quartile, individuals in the highest quartile of red meat intake at age 45–74 years had a higher risk of cognitive impairment at age 61–96 years; this effect was weaker for poultry intake.³⁷ Meat intake in childhood and early adulthood seems to have little effect on cognition, with small amounts of evidence generally. However, the data indicate that red meat intake in older adulthood can be associated with cognitive deficits, but might have weak protective effects in specific cognitive domains.

Fish

The relationship between fish intake and cognitive function is complex as fish contains beneficial nutrients, such as long-chain n-3 polyunsaturated fatty acids (PUFAs), but could also be a source of contaminants (eg, mercury and dioxins). Children who consumed a spread made of fish flour for 6 months showed improved verbal learning ability and memory compared with children who consumed a placebo spread made of superfine rusk bread flour.³⁸ When adjusting for dietary compliance, children who consumed an oily fish lunch three times a week for 16 weeks showed improved intelligence scores compared with children who consumed a meat-based lunch.³⁹ Cross-sectional evidence further indicates that consuming 8 g of fish per day in childhood and adolescence increased the likelihood of high academic test scores by 1 point compared with individuals who consumed little or no fish.⁴⁰ However, a non-linear relationship is evident, in which academic achievement decreases with the highest amounts of fish consumption, potentially due to the presence of mercury and other contaminants. High amounts of hair mercury, which were significantly associated with canned fish intake but not total fish intake, were associated with deficits in general cognitive, memory, and verbal abilities.⁴¹ Similarly, high fish intake is associated with improved vocabulary and grades, but exceeding the recommended national guidelines for docosahexaenoic acid or eicosapentaenoic acid was not beneficial.⁴²

Studies of the effects of fish consumption on cognitive function in adulthood are scarce. However, one

cross-sectional study showed that although a high intake of seafood—particularly large-mouth fish, such as tuna—increases amounts of mercury in the blood, it is also associated with increased blood n-3 PUFAs. These increased n-3 PUFAs are associated with improved cognition (up to three servings of large-mouth fish per week). The positive effects of n-3 PUFAs can be counteracted by high mercury intake, leading to worsened cognitive function when plasma mercury concentrations are more than 15 µg/L.⁴³

The long-term protective effects of fish against cognitive decline in older adults have been shown repeatedly. Consuming at least four servings of fish per week leads to memory scores similar to individuals who are 4 years younger.⁴⁴ Consuming one fish meal per week is associated with a 10% reduction in the rate of cognitive decline and consuming two fish meals per week is associated with a 13% reduction in the rate of cognitive decline.⁴⁵ In a Japanese cohort, there was an inverse association between fish consumption and the onset of dementia, with an odds ratio of 0·84. This inverse association could lead to 5·6% fewer cases of dementia, which equates to 2·6 million preventable cases worldwide if fish intake is equivalent to the highest quintile of consumption (eg, >85·7 g/day).⁴⁶ Participants in the Older People And n-3 Long-chain Polyunsaturated Fatty Acids⁴⁷ cohort who reported regular consumption of oily fish performed consistently better on cognitive tests. Furthermore, participants who reported eating the largest amounts of oily fish, distinct from white fish, showed the highest rates of cognitive function.⁴⁸

However, some studies have shown little to no beneficial effect of fish consumption. An analysis of the SU.VI.MAX study found no association between fish intake and MMSE performance, although a high self-reported consumption of fish was associated with fewer cognitive complaints.⁴⁹ Although cognitive complaints are self-reported and highly subjective, this outcome is indicative of an improved quality of life.

Eggs

No studies have assessed the effects of egg consumption on cognitive function in young age. In older adults, a 4-year follow-up of men showed a positive association between high egg intake and cognitive function. Specifically, each additional half egg per day was associated with improved performance on the trail-making test and verbal fluency test.⁵⁰ However, these improvements were not replicated in participants from the Health and Retirement Study.⁵¹ Although moderate egg consumers (individuals who ate two to six eggs per week) had the best cognitive performance at baseline, there was no association between egg consumption and cognitive change long term.⁵²

Legumes

Research investigating the effect of chronic legume consumption on cognitive function is scarce, with most

evidence coming from soy-based protein. Multiple studies have investigated the effects of soy-based protein in postmenopausal women for durations between 16 weeks and 2·5 years, but showed no effects on cognitive function.^{53–55}

In older adults, high total bean and total soy-based product consumption showed favourable effects on cognitive function in women.⁵⁶ Moreover, a positive association between high legume consumption and improvement in MMSE score after 1 year was shown.⁵⁷ By contrast, high tofu intake, a soy-based food, has been consistently shown to impair memory and verbal learning in old age.^{58,59} In men, poor cognitive test performance and indications of increased brain atrophy were also significantly associated with high tofu consumption in adulthood.⁶⁰

Nuts

A 2019 systematic review of nut consumption across the life course revealed potential protective effects on some cognitive domains.⁶¹ However, cross-sectional and prospective cohort studies have unclear results.⁶¹ These protective effects also seem to be independent of the type of nuts consumed, amount of nuts consumed, and participant age. In a randomised controlled trial (RCT) of young adults aged between 18 years and 25 years, inferential verbal reasoning was significantly improved after 8 weeks of consuming walnut-containing banana bread compared with placebo-containing banana bread, with no apparent effects on memory and non-verbal reasoning.⁶² However, long-term almond consumption did not improve cognitive function when consumed by adults who were overweight or obese (BMI 25–40) as part of a weight loss intervention.⁶³

Evidence indicates that nuts might positively affect cognitive function. A large sample of older adult women showed positive associations between high long-term nut intake and mean cognitive status for all cognitive outcomes that were measured. Furthermore, women consuming at least five servings of nuts per week had better global cognition than women who did not consume nuts.⁶⁴ A cross-sectional analysis of the China Health and Nutrition Survey⁶⁵ cohort showed that individuals who consumed more than 10 g of nuts per day had significantly higher global cognitive function scores than individuals who consumed less than 10 g of nuts per day. Furthermore, only 8·4% of individuals who consumed high amounts of nuts showed poor cognitive function compared with 17·8% of individuals who did not consume nuts.⁶⁶

However, an RCT published in 2020 contradicted these findings.⁶⁷ A diet intervention with walnuts for a period of 2 years, accounting for 15% of the total daily energy intake compared with a control group who did not have walnuts, showed no delay in cognitive decline. However, this RCT was conducted at two separate sites; a subset of participants from one site who showed improved global

cognition had less education and lower dietary α -linolenic acid (ALA; an omega-3 essential fatty acid) values compared with the control group. Moreover, functional MRI examination of this subset of participants showed significantly less functional brain activity during a working memory task compared with control participants despite both groups having equal scores on the task, suggesting improved brain efficiency.⁶⁷

Total and specific fatty acids and sources of fats

A 2015 study showed improved cognitive flexibility in children with low consumption of saturated fats, whereas increased saturated fat and dietary cholesterol intake were associated with impaired working memory and cognitive control, particularly in the most difficult cognitive challenges.⁶⁸ However, a large cross-sectional study showed that total fat and saturated fat intake were not associated with achievement or intelligence test performance in young individuals.⁶⁹

Some acute effects of fat consumption have been observed in young adults aged between 18 years and 37 years. For example, acute administration of rapeseed oil (16 g; 10% ALA) improved attention and processing speed when compared with a calorie-free placebo.⁷⁰ In a randomised, placebo-controlled study, consumption of an equicaloric milkshake containing walnut oil (30 mL; 12% ALA), compared with a milkshake containing saturated fat (cream; 85 mL), led to quicker hippocampal-dependent learning.⁷¹

A longitudinal, population-based study of participants with a mean age of 50 years at baseline and 71 years at follow-up showed that, at midlife, high intake of saturated fatty acids from milk products was associated with impaired global cognitive function.⁷² Furthermore, the risk of mild cognitive impairment (MCI) was increased when saturated fat consumption increased.⁷²

A 2019 meta-analysis of older adults showed no associations between cognitive decline and total fat consumed.⁷³ However, high saturated fat intake was associated with an increased risk of cognitive impairment with a relative risk of 1.4.⁷³ Furthermore, analysis of the CHAP cohort revealed increased decline in verbal recall, MMSE, and concentration in those with high consumption of saturated and transunsaturated fats.⁷⁴

Sugars and sweeteners

Sugar consumption during pregnancy and childhood, especially from sugar-sweetened beverages, and consumption of diet fizzy drinks (eg, fizzy drinks without added caloric sweeteners) during pregnancy were associated with adverse effects on cognitive function in early and late childhood.⁷⁵ Sugar consumption in mothers and children was more than the amount recommended by the EAT–Lancet reference diet. However, a meta-analysis in 1995 showed that sugar does not affect the behaviour or cognitive performance of children.⁷⁶ In adults, consumption of glucose has shown a beneficial

effect on immediate recall tasks in verbal memory assessments.⁷⁷

A meta-analysis of interventional and observational studies showed no effects on cognitive function of consumption of sweeteners in children or adults.⁷⁸ Compared with sugar consumption, however, multiple studies showed that consumption of the artificial sweetener aspartame is associated with poor cognitive performance.^{79,80} A small crossover study in healthy adults showed consumption of a high-aspartame diet for 8 days, compared with a low-aspartame diet, resulted in worse spatial orientation, but did not affect working memory.⁸¹

Sugars and sweeteners have consistently been shown to be detrimental for cognitive function in older adults. Exploratory analysis of older adults showed that high fructose and glucose intake was associated with MCI.⁸² Furthermore, the risk of cognitive impairment at the hundredth percentile (68.82 g of sugar per day) was 3.3–3.6 times larger based on total sugar, sucrose, and free sugars intake compared with the twenty-fifth percentile of intake (26.22 g of sugar per day).⁸² Similar findings were reported in an analysis of Puerto Rican older adults, in which each 60 g increase in total sugar intake was associated with a decrease of 0.4 points in the MMSE.⁸³ Regular fizzy drinks contain approximately 38 g of sugar per serving and show significant inverse associations with global cognitive function, working memory, and executive function.⁸⁴

Discussion

The EAT–Lancet Commission devised a diet that can be adopted in different cultures to support sustainability and produce a global change in food production and food waste, alongside improving human health.¹ This Review attempted to increase the understanding of the health effects of the reference diet by evaluating whether the consumption of the guideline amounts of each food group could support optimal cognitive function across the life course (figure). Optimal cognitive function is a crucial aspect of brain health and wellbeing. Cognitive decline and age-related neurocognitive pathologies are leading contributors to disability.⁸⁵

The synthesis of the literature showed numerous important limitations of the evidence base, which make definitive conclusions about diet and cognitive function premature. The evidence base is scarce; few studies are done on specific food groups either in general or within specific age groups. Evidence pertaining to the effects of legumes, fish, and meat on cognitive function are mostly restricted to specific subcomponents (ingredients within that food group). Regarding legumes, for example, most literature investigates soy-based products but no other legumes, such as lentils or chickpeas. Similarly, research on the effects of meat on cognitive function is largely restricted to red meat and does not evaluate poultry. There are no studies of effects of seafood other than fish, such as mussels and clams, despite shellfish also being

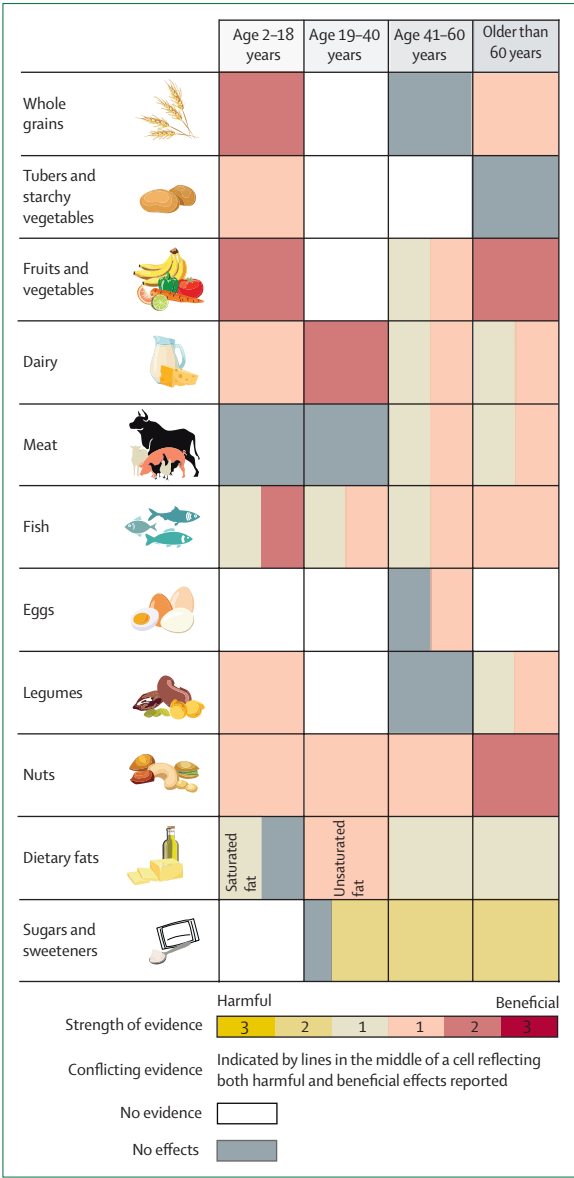


Figure: Effects on cognitive function of consuming components from each food group across the life course, according to the strength of the reviewed evidence

A semiquantitative approach was used to display data. Dark colour gradients indicate strong evidence (eg, systematic reviews, meta-analyses, and randomised controlled trials). Light colour gradients indicate weak evidence (eg, small prospective cohort studies and cross-sectional studies). The intensity of a gradient increases as the number of studies that support the beneficial or harmful effect of the food group increases. No evidence is indicated by a blank cell. Null findings are indicated by grey cells. For conflicting evidence, instead of using grey cells the conflicting nature of the evidence was shown by applying the corresponding colour, intensity, and gradient.

good sources of omega-3 fatty acids and potentially better for planetary health than fish.⁸⁶

The reference diet reflects the needs of a man aged 30 years (weighing 70 kg) or a woman aged 30 years (weighing 60 kg) with a BMI of 22. Willet and colleagues¹ acknowledge that everyone in the global population is

not expected to consume the same diet or provide detailed quantity ranges per food group to allow for variations in diet depending on world cuisines and dietary patterns. This Review examines the evidence in different age groups as the nutritional requirements for optimal cognitive function could be different for children and adolescents compared with adults and older adults.^{87,88} For example, current evidence suggests that meat consumption is not associated with cognitive function in children and adolescents, but that high meat intake in adulthood and in older adulthood could be detrimental to cognitive function (figure, table). Evidence about the long-term effects of diet on cognitive function across the life course in various populations is inadequate, with implications for dietary guidelines such as the EAT–Lancet reference diet.

The recommended intake ranges of each food group of the EAT–Lancet reference diet are wide, as they are designed to consider the availability of individual food components to individuals worldwide. However, these wide ranges allow for large variations in diet, which might not be beneficial for cognitive function or brain health and could be detrimental. Investigating the extremes of food intake is challenging but investigating specific dietary patterns could improve the understanding of the issue of potential low or high intake of some food groups. Extreme dietary patterns, such as the ketogenic diet, might provide an insight into the cognitive effect of extremely low and high intakes of particular foods. However, studies in disease-free human participants are scarce. Plant-based dietary patterns that include little or no amounts of animal-sourced foods sustain good cognitive function in adulthood and old age.^{89–91} The EAT–Lancet reference diet can be considered a healthy dietary pattern that is similar to other predominantly plant-based diets, such as Mediterranean, Dietary Approaches to Stop Hypertension (DASH), and Mediterranean-DASH Intervention for Neurodegenerative Delay, all of which have repeatedly been associated with a reduced risk of cognitive impairment.^{91,92} These diets recommend low (rather than no) intake of meat and fish. Considering the known importance of some micro-nutrients and food metabolites for optimal brain function (eg, flavonoids, iron, and specific vitamins),⁹³ revising dietary recommendations with the aim of maintaining an adequate nutrient intake to sustain healthy cognitive function across the life course could be useful.

The majority of the evidence analysed in this Review is based on cross-sectional analyses that, despite large sample sizes and statistical control for potential confounders, do not provide causal conclusions. These cross-sectional studies mostly rely on self-report and recall-based food frequency questionnaires, which are prone to bias and socially desirable reporting.⁹⁴ In addition, these studies have variability in methods of food preparation, which can affect the composition and nutrient status of food when ingested. Cooking and food processing affect the phytochemical content of

	EAT-Lancet reference diet recommendation	Conclusions from available evidence
Whole grains	232 g/day of whole grains (rice, wheat, corn, and other [mix and amount of grains can vary]) with a range of 0–60% of energy comprising 811 kcal/day	Evidence shows a positive association between whole grain intake and executive function in children and adolescents; the recommended amounts of the reference diet show favourable effects on cognitive function in these age groups; conclusions cannot be made for effects in older adults, but the beneficial effects of high whole grain consumption on cardiometabolic health could contribute to improved cognitive function
Tubers and starchy vegetables	50 g/day of tubers or starchy vegetables, specifically potatoes and cassava, with a range of 0–100 g comprising 39 kcal/day	Previous studies have administered amounts of carbohydrates similar to the recommendation; however, because there are few studies, and available studies have small sample sizes and heterogeneous findings, further work is required to investigate the effects of chronic consumption on cognitive function across the life course
Fruits and vegetables	300 g/day of vegetables with a range of 200–600 g comprising 78 kcal/day; 200 g/day of fruits with a range of 100–300 g comprising 126 kcal/day	High fruit and vegetable consumption seems to benefit cognitive function across the lifespan, especially in older adults; however, the available evidence precludes conclusions regarding specific quantities; the recommendations for intakes of dark green, red, orange, and other vegetables (100 g/day of each) are consistent with the benefits of consuming various vegetables shown in current studies
Dairy	250 g/day of dairy foods (whole milk or derivative equivalents) with a range of 0–500 g comprising 153 kcal/day	The recommended 250 g/day is equivalent to approximately 1 glass of whole milk that would be appropriate for maintaining cognitive function during ageing according to current evidence; however, the effects of dairy food consumption, particularly in older adults, might be dependent on amount, type, and fat content; further research in different age groups is required
Meat	7 g/day of beef, lamb, or pork with a range of 0–14 g comprising 15 kcal/day; 29 g/day of chicken or other poultry with a range of 0–58 g comprising 62 kcal/day	Available evidence precludes conclusions about specific quantities of meat intake; generally, meat intake does not seem to affect cognitive function in children and young adults; however, red meat intake seems to be associated with cognitive deficits in older individuals despite little evidence of weak protective effects on some specific cognitive domains; more studies are needed to establish recommendations for an optimal range of meats from different animal sources
Fish	28 g/day of fish with a range of 0–100 g comprising 40 kcal/day	The available evidence is consistent with current recommendations; high fish consumption is favourable for the maintenance of cognitive function across the lifespan but should be reduced or avoided when the available fish contains high amounts of mercury or other contaminants (eg, polychlorinated biphenyls and polybrominated diphenyl ethers) as these contaminants can counteract the positive effects of fish on cognitive function
Eggs	13 g/day of eggs with a range of 0–25 g comprising 19 kcal/day	The recommended 13 g/day is equivalent to half an egg each day or 1 whole egg 3 or 4 times a week; the few available studies indicate that egg consumption within the current recommended range has either no association with cognitive function or could be favourably associated with cognitive function
Legumes	50 g/day of dry beans, lentils, or peas with a range of 0–100 g comprising 172 kcal/day; 25 g/day of soy-based foods with a range of 0–50 g comprising 112 kcal/day; 25 g/day of peanuts with a range of 0–75 g comprising 142 kcal/day	There is little evidence on the effects of various legume types on cognitive function across the lifespan and the available evidence precludes conclusions regarding quantities; however, high legume consumption seems beneficial in general, with the exception of tofu (a soy-based product that is associated with detrimental effects on cognitive function); research on the effects of other legumes on cognitive function across the lifespan is needed
Nuts	25 g/day of tree nuts comprising 149 kcal/day	The recommended amount is within the range assessed in the literature (10–60 g/day); evidence suggests that adults should consume at least 10 g of nuts per day and although high consumption (>30 g/day) does not exhibit negative effects on cognitive function, it might not provide a benefit
Dietary fats	6.8 g/day of palm oil with a range of 0–6.8 g comprising 60 kcal/day; 40 g/day of unsaturated oils with a range of 20–80 g comprising 354 kcal/day; 5 g/day of lard or tallow with a range of 0–5 g comprising 36 kcal/day	The available evidence differentiates between different sources of added fats, with unsaturated fat associated with better cognitive function than saturated fat; consequently, higher unsaturated oil intake relative to other added fat sources is recommended; acute intervention studies support the recommendations for specific quantities but long-term studies of intake of various types of added fats in cognitive function are needed
Sugars and sweeteners	31 g/day of sweeteners with a range of 0–31 g comprising 120 kcal/day	Restricting the intake of sugars and sweeteners to 26 g/day, particularly in older adults, might be better for cognitive function

Table: Qualitative evaluation of literature findings for specific food groups relative to the recommended intake of the EAT-Lancet reference diet to meet nutritional requirements for adults and children older than 2 years

vegetables, either by reducing nutrient concentration or softening the matrix and increasing their extractability.⁹⁵ Therefore, self-report assessments of food preparation could be important in overcoming the contradictory findings shown in some observational studies. Ideally, RCTs should be done to evaluate individual components of each food group and assess the association between the amount of each food group consumed and its affect

on cognitive function in different age groups.⁹⁶ However, RCTs are challenging to do on a large scale with long-term interventions, particularly in children, in whom dietary compliance might be low. Moreover, in some studies there is an increased likelihood of false positive results because of multiple comparison issues arising from the analysis of cognitive outcomes with cognitive tests.

Panel: Limitations of identified evidence and recommendations to overcome these limitations

No evidence for particular food groups in specific age groups

- Research should consider the diet of an individual in its entirety and consider possible interactions between all food groups
- High-quality and relevant data at all stages of the life course are needed

Recommendations:

- Systematically investigate the effect of each food group on cognitive function; ideally this investigation will be done through randomised controlled trials with the average required intake of a food or of multiple foods within a food group specified by the EAT–Lancet diet or through prospective cohort studies in which people consume a wide range of subcomponents of a food group
- Systematically study the effect of each food group on cognitive function within each age group

Most evidence is based on cross-sectional analyses

- Most cross-sectional analyses measure multiple outcomes
- The risk of false positives is high when multiple measures of cognitive function are assessed and when confounders affect the interpretation of findings

Recommendations:

- Use data from existing large-scale prospective cohort studies that include data on dietary exposure and in which cognitive function data have been or could be collected
- To minimise measurement error, prioritise doing studies with repeated estimates of dietary exposure

Scarce evidence of effects of chronic intake of specific foods or multiple foods within a food group

Recommendations:

- Medium-term and long-term randomised controlled trials to investigate the effects of consuming specific foods or multiple foods within a food group on cognitive function are required
- Consider doing studies that include real-life settings (eg, low-income areas) where baseline diet might be of poor nutritional quality and where there is potential to see changes in cognitive function

Self-report and recall-based food frequency questionnaires

Recommendations:

- Define and measure biomarkers of food intake
- Increase the use of prospective dietary assessment (eg, with detailed daily food diaries as opposed to recall-based food frequency questionnaires)

In the future, some of the limitations of cross-sectional studies and the challenges associated with conducting RCTs could be overcome by long-term and large-scale prospective cohort studies that quantitatively examine relationships between cognitive function and the intake of individual whole foods. Prospective cohort studies and meta-analyses would be improved by using biochemical markers related to cooking methods. For example, in a secondary analysis of data from a large representative sample of older adults in the USA ($n=3632$),⁹⁷ self-reported walnut intake was measured for 1 year and converted into the average number of walnut servings per day. Participants were then put into one of three groups (no walnut intake, low walnut intake [0·01–0·08 servings weighing 28 g per day], or moderate walnut intake [$>0\cdot08$ servings weighing 28 g per day]). Latent growth

Search strategy and selection criteria

Data for this Review were identified by a search of PubMed and a further manual examination of references from the returned articles. A non-exhaustive but specific search strategy was used to ensure sufficient coverage of the existing evidence in humans only. Therefore, generic terms were used instead of multiple searches for each cognitive domain per food group. The search terms “cognition”, “cognitive function”, and “cognitive decline” were searched alongside the food group terms “whole grains”, “tubers”, “starchy vegetables”, “fruits”, “vegetables”, “dairy”, “meat”, “fish”, “eggs”, “legumes”, “nuts”, “dietary fats”, “sugars”, and “sweeteners”. Randomised controlled trials and meta-analyses were used primarily as the strongest sources of evidence, then prospective cohort studies and cross-sectional analyses where there was scarce strong evidence. The reported associations from cross-sectional analyses were controlled for confounders unless otherwise reported. Only studies examining the relationship between whole foods with normal cognitive development and cognitive ageing in individuals who were healthy, disease-free, and community-dwelling were included. Studies with participants from age 2 years to 99 years were included to represent the population at whom the reference diet is aimed, and only studies published in English were included. Studies examining the effects of nutritional supplements were excluded to better reflect the expected food intake when following the reference diet. Evidence was considered at a food (eg, blueberries) or food group (eg, fruits) level.

modelling revealed that, during a 4-year observational period, low to moderate walnut intake was associated with higher cognitive scores compared with no walnut intake. However, walnut consumption was not associated with rate of cognitive change over time.

In conclusion, this Review evaluated the EAT–Lancet reference diet recommendations regarding its effects on cognitive function in humans (table) using existing literature about the effects of different food groups. A bias score based on the reviewed articles was not computed. However, sources of bias are heterogeneous, including funding sources, involvement of industry, participant selection, error in measurement of the exposure or outcome, including individuals with exposures other than those specified in the study methods, missing outcome data, selective reporting, and publication bias.^{91–94} There is little high-quality, strong causal evidence of the effects of individual foods on cognitive function across the life course. Recommendations for potential future avenues of research have also been provided in this Review (panel). Overcoming the limitations of current research would allow the implications of following an environmentally sustainable dietary pattern to be assessed not only in terms of the reduction in the incidence of non-communicable diseases and reduced mortality rate, but

also in terms of brain health (particularly cognitive function) throughout the life course.

Contributors

BD and CK contributed equally to the conceptualisation, writing, reviewing, and editing of this manuscript. AC, ERG, MVG, GLF, SL, JCM, and DV reviewed and edited the manuscript. LG reviewed and edited the manuscript and supervised the project administration. JMV and ST conceptualised and wrote the original draft, reviewed and edited the manuscript, and supervised the project administration.

Declaration of interests

AC received consulting fees from UK Climate Change Risk Assessment. ERG received research grants from Enterprise Ireland and dairy companies as part of Food for Health Ireland Technology Centre (TC20180025) and from Aconsi. ERG is an academic supervisor for the Marie Curie Career-FIT programme; no funds were received from the commercial partner Marigot. The programme of work was developed in collaboration with the commercial partner Marigot. ERG received honoraria from Nestlé Research Centre to speak at a conference. She is a member and trustee of the Nutrition Society, Deputy Director of University College Dublin Institute of Food and Health, and a member of the governing authority the European Food Information Council. JMV is a former employee of Danone Nutricia. GLF is an employee of DSM. LG is a former employee of International Life Sciences Institute (ILSI Europe). The European branch of the International Life Sciences Institute paid the processing charges for this manuscript. All other authors declare no competing interests.

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