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Refined carbohydrate-rich diet is associated with long-term risk of dementia and Alzheimer's disease in apolipoprotein E ε4 allele carriers

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Abstract

Introduction: In animal models, refined carbohydrates (RF)worsen Alzheimer's disease (AD). However, the long-term effects of high RF intake on the risk of dementia and AD are poorly described in epidemiological studies. Moreover, the interaction between RF and the apolipoprotein E ε4 allele (APOE- ε4) is unknown. Our study investigated whether RF-rich diets are associated with the risk of dementia and AD.

Methods: The glycemic load (GL) was quantified in 2777 elderly participants from the French Three-City Study to estimate RF intake. Then, the associations between GL and risk of dementia and AD, and the interaction with APOE- ε4 over a 12-year period were assessed using proportional hazards models.

Results: After adjustment for potential confounders, high afternoon-snack GL was associated with increased dementia and AD risk in APOE- ε4 carriers (hazard ratio = 1.27 [1.03–1.56]).

Discussion: This study highlights that RF-rich diets are a risk factor for dementia and AD in APOE-ε4 carriers.

KEYWORDS: Alzheimer's disease, apolipoprotein E ε4, cohort study, dementia, diet, glycemic load, refined carbohydrate, sugar

1. Introduction

According to the World Health Organization, dementia will affect >152 million people by 2050 [1]. Currently no effective treatment is available to cure or slow down dementia progression. After the repeated failure of clinical trials, now the most promising research focuses on preventing dementia. Therefore, it is urgent to identify modifiable factors that could be targeted in interventions to prevent dementia and to promote better brain health in aging populations. Among these modifiable factors, nutrition has emerged as an important issue [2], particularly the steady increase in the consumption of refined carbohydrates [3]. Refined carbohydrates are carbohydrates that are rapidly absorbed into the bloodstream, and include starches and sugars (sucrose, glucose-fructose syrup). The glycemic and insulinemic responses progressively increase with more processed carbohydrates. Moreover, some meals are typically high in refined carbohydrates (i.e., breakfast and afternoon snack) [4], suggesting that they are at greater risk of inducing large glycemic and insulinemic responses.

In mouse models of Alzheimer's disease (AD), high sugar diet worsens AD pathophysiology, notably by causing memory impairment and increasing amyloid beta (Aβ) deposits. These studies also demonstrated that a high-sugar diet alters brain insulin signaling and leads to insulin resistance [5,6]. This suggests that diets rich in refined carbohydrates could promote dementia and AD through insulin resistance [7]. However, insulin resistance and refined carbohydrate-rich diet are important risk factors of type 2 diabetes (T2D), therefore T2D could be a confounder in the relationship between refined carbohydrate-rich diet and dementia.

To date the direct association between refined carbohydrate-rich diet and the risk of dementia or cognitive decline has not been adequately investigated in epidemiological studies [8,9], as they have been mostly cross-sectional studies with small sample sizes. They showed that refined carbohydrates consumption is associated with higher amyloid deposits [10], lower entorhinal cortical thickness [11], and poorer cognitive performance [12]. The few existing longitudinal studies have yielded inconsistent results [13–15].Moreover, a wide range of methods have been used to assess

carbohydrate consumption: self-reports [13], adherence to a dietary pattern [10], percentages of calories from carbohydrates [11], glycemic index and/or glycemic load (GL) [12,14,15].

Previous epidemiological studies also suggest that a refined carbohydrate-rich diet may interact with the apolipoprotein E ε4 allele (APOE-ε4), the principal genetic risk factor of AD and dementia. In animal studies, APOE-ε4 carriers are more likely to develop insulin resistance [16], and this could be exacerbated by consumption of refined carbohydrates [5,6]. Nevertheless, the potential interaction between a refined carbohydrate-rich diet and APOE-ε4 on the risk of dementia has not been studied in humans.

The objective of this study was to determine whether high refined carbohydrate intake, estimated by quantifying the GL, is associated with the risk of dementia in a large population-based prospective cohort study with a 12-year follow-up (the Three-City Study). The present study addressed four questions: (1) Is a refined-carbohydrate rich diet associated with dementia? (2) Are some meals more at risk than others? (3) Does refined carbohydrate-rich diet interact with APOE-ε4? (4) Is the association independent of T2D?

2. Methods

2.1 Study participants

The Three-City Study is a French population-based cohort study of 9294 people, aged 65 years and over, who were randomly selected between 1999 and 2000 from the electoral roll of three French cities: Bordeaux, Dijon, and Montpellier. A detailed description of the Three-City Study has been provided elsewhere [17]. Participants had face-to-face interviews with trained nurses and psychologists at baseline, and at 2, 4, 7, 10, 12, and 15-years follow-up (FU; Figure 1). Questionnaires were used to collect data on sociodemographic and lifestyle characteristics, education level, self-reported chronic diseases, depressive symptoms, and functional status. In addition, participants underwent a comprehensive evaluation of cognitive and physical functions. The present study focused on a subsample of participants from Bordeaux (n = 1755) and Montpellier (n = 1690) who

filled in the food frequency questionnaire (FFQ) at the first and second follow-up (i.e., 2 and 4 years after baseline), respectively (Figure 1). Participants with prevalent dementia at the time of FFQ completion were excluded. A flow chart describes the participants' selection (Figure 2). At the end of the study, the mortality rate was 26.9% and the rate of lost participants in the FU was 21.0%. The Ethical Committee of the University Hospital of Bicêtre (France) approved the study protocol, and all participants signed an informed consent.

2.2 Dietary data

2.2.1 Food Frequency Questionnaire

Dietary data were collected using a semi-quantitative, 148-item FFQ at 1-FU for Bordeaux and 2-FU for Montpellier (Figure 1). The FFQ was divided into: breakfast, lunch, dinner, and snacks between meals (extract from the FFQ in Table S1 in supporting information). Reported frequencies were transformed into discrete variables as follows: 0 for never or less than once a month, 0.25 for once a month, 0.5 for twice a month, 0.75 for three times a month, 1 to 7 for one to seven times per week [18]. Discrete variables were expressed in servings per week.

2.2.2 24-h dietary recall interview

A 24-hour dietary recall interview was performed at the Bordeaux center at 1-FU by trained dieticians. For each item, seven serving sizes were available. Concordance between FFQ and 24-hour dietary recall was previously checked for fatty acids [19].These data were only used in sensitivity analyses.

2.2.3 Glycaemic load

The glycemic index values of FFQ items were obtained from the International Table of Glycemic Index [20] and internet updates (www.glycemicindex.com), using glucose as the reference. The glycemic index compares the rate of glucose release by measuring the 2 hours postprandial glycemia after consumption of a food portion containing 50 g of available carbohydrates. GL reflects both the carbohydrate quantity and quality [20,21]. Compared to low-GL diets, high-GL diets elicit larger

glycemic and insulinemic responses [9,12,20]. For each FFQ item (i.e., food/beverage categories), GL was calculated by multiplying the glycemic index by the amount of available carbohydrates (g) per serving, divided by 100 [22]. Foods with low carbohydrate content (e.g., meat, fish, fats) were not assigned any GL value [23]. Then, the GL for each item was multiplied by the frequency of consumption/week reported by each participant. Finally, the sum of this last value for all the items consumed during a meal gave the total GL for breakfast, lunch, afternoon snack ("goûter" in French, corresponding to a snack between lunch and dinner), and dinner. The GL from the 24-hour dietary recall was estimated using precise food item data and gathered by meal. The daily GL was either the sum of all the FFQ items or the 24-hour dietary recall. The total GL values for breakfast, lunch, afternoon snack, and dinner from the FFQ and the 24-hour dietary recall were significantly correlated in the Bordeaux subsample (range: 0.30 to 0.57). Precise estimation of carbohydrate content was not possible with this FFQ.

2.2.4 Energy intake

Energy intakes for the corresponding items in the FFQ were obtained from the Anses-Ciqual database (www.anses.ciqual.fr). The energy intake per serving of each item was multiplied by the reported frequencies. Then, the sum of the energy intake for the items consumed at each eating occasion gave the energy intake of each meal. The energy intakes from the 24-hour dietary recall were derived as previously described [19]. Although the FFQ underestimated the energy intake, the energy intakes for breakfast, lunch, afternoon snack, and dinner from the FFQ and the 24-hour dietary recall in the Bordeaux subsample were significantly correlated (range: 0.20 to 0.53).

2.2.5 Mediterranean-like diet score

To take into account the diet quality, a Mediterranean-like diet score was calculated. Items were grouped according to the nine components of the Mediterranean-like diet score [24,25]. For fruits, vegetables, legumes, cereals, and fish, one point was assigned when the participant's consumption was above the median, zero otherwise. For meat and dairy, one point was assigned when the

participant's consumption was below the median, zero otherwise. For alcohol, one point was assigned when consumption was below 20 g of ethanol per day for men and 5.7 g for women (i.e., low-to-moderate alcohol consumption in this population). For the ratio of monounsaturated fatty acids to saturated fatty acids, one point was assigned when the ratio was above the sex-specific median, zero otherwise. The total Mediterranean like diet score ranged from zero (lowest adherence) to nine (highest adherence).

2.3 Diagnosis of dementia

The diagnosis of dementia and its classification was made at each follow-up by the Three-City Study local clinical investigators, following standardized procedures. Then, an independent committee of neurologists examined all potential cases of dementia to obtain a consensus on the diagnosis and etiology based on the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition [26]. Cases of dementia, including AD, were classified according to the National Institute of Neurological and Communicative Disorders and Stroke/Alzheimer's Disease and Related Disorders Association criteria [27], and cases of mixed/vascular dementia according to the National Institute of Neurological Disorders and Stroke/Association Internationale pour la Recherche et l'Enseignement en Neurosciences criteria [28]. Mixed dementia was defined as an AD-type cognitive profile with either cerebrovascular lesions on brain imaging, or a documented history of stroke and presence of prominent executive function deficits, attested by the Trail Making Test [29].

2.4 Covariates

Education level was defined as no school, primary school, high school, or graduate level. The Mini-Mental State Examination [30] was used as an index of global cognitive performance. Body mass index (BMI) was calculated as weight (kg) / height (m^2). Hypertension was defined by systolic blood pressure $\geq$140 mmHg, or diastolic blood pressure $\geq$90 mmHg, or use of antihypertensive drugs [31]. History of head trauma and stroke was established using standardized questions. Cardiovascular history included history of myocardial infarction, coronary surgery, coronary angioplasty, and arterial

surgery of the legs for arteritis. Hypercholesterolemia was defined as total cholesterol ≥6.2 mmol.L^{-1}. T2D was defined as treated diabetes, fasting glycaemia >7 mmol.L^{-1}, and additionally self-reported. APOE genotyping was described elsewhere [32]. APOE-ε4 carriers had at least one ε4 allele. Information was also obtained on the subjectively evaluated health and smoking status (never, past, or current). Depressive symptomatology was evaluated with the Center for Epidemiological Studies-Depression (CES-D) scale [33], using the recommended French cut-off scores at 17 and 23 points for clinically relevant depressive symptom burden in older men and women, respectively [34]. As physical activity was assessed in a slightly different manner in the two centers [35], a common binary variable was defined (none or low/regular).

2.5 Data analysis

2.5.1 Covariates selection

First, the main confounding factors of dementia and potential confounding factors related to carbohydrates were pre-selected. For the outcome-related covariates (dementia) proportional hazard models adjusted for center, age, sex, and education were performed. For exposure-related covariates (daily GL) Pearson correlations (for continuous variables) or analysis of variance (ANOVA; for categorical variables) were used. In both cases, covariates with a P value < .10 were selected.

2.5.2 Main analyses

Proportional hazards models were used to evaluate the association between the GL and the risk of all-cause dementia over the 11- to 13-year follow-up (mean follow-up = 11.4 ± 2 years), in five separated analyses (i.e., daily, breakfast, lunch, afternoon snack, dinner). This modeling considers the time of dementia onset and the participants out of the study (i.e., death, loss of follow-up). In Model 1, analyses were adjusted for age (at the time of the FFQ), sex, education, APOE-ε4 carrier status, BMI, T2D, hypertension, cardiovascular history, stroke, hypercholesterolemia, head trauma, good subjective health, and tobacco (i.e., the main confounding factors of dementia) [36]. In Model 2, Mediterranean diet–like score and physical activity were also added relative to the Model 1, due to

the high percentage of missing values (6.7% for the Mediterranean diet–like score and 14.3% for physical activity). In Model 3, incomplete variables were imputed (see below) and analyses were adjusted for the same variables as in Model 2. The interaction between GL and APOE-ε4 was tested and was kept in the model when significant. The proportional hazards assumption was tested with the Schöenfeld residuals method. Kaplan- Meyer survival curves were used to graphically illustrate survival findings.

2.5.3 Imputation of missing values

The percentage of missing values across covariates varied between 0% and 14.3%. To minimize the loss of power and selection bias, incomplete variables were imputed using the mice package [37]. To include a large number of related predictor variables without encountering problems due to collinearity [38], we used the random forest method. Eight multiply imputed datasets were created and analyzed. The parameters of interest were estimated in each imputed dataset separately, and combined using Rubin's rules. The combined results of the imputed datasets are presented in Model 3.

2.5.4 Sensitivity analyses

First, the main analyses concerning participants from Bordeaux were replicated using the GL values estimated from the 24-hour dietary recall results. Then, participants (both centers) with T2D were excluded to confirm that GL effect was not mediated by T2D (T2D participants had reduced GL values). Finally, analyses were restricted to AD by excluding participants (both centers) with incident mixed and vascular dementia from the main analyses.

3. Results

A total of 2777 participants (n = 1376 from Montpellier and n = 1401 from Bordeaux) were included in the analyses (Table 1, Table S2 in supporting information). At the time of the FFQ, the participants'

mean age was 75.9 years, 61.1% were women, and 10.1% had T2D. During a mean follow-up time of 11.4 years (SD = 2.0 years), 350 participants developed dementia: 260 cases of AD, 49 cases of mixed dementia, and 41 cases of vascular dementia were identified.

3.1 The statistical interaction between glycaemic load and APOE-*ε4 carrier status is associated with the risk of dementia*

We asked whether the GL, as an estimation of refined carbohydrate consumption, was associated with the risk of dementia during the 11.4 years of follow-up (Table 2). We did not find any direct association between dementia and the daily GL or GL value of breakfast, lunch, afternoon snack, and dinner. However, the interaction between afternoon-snack GL and APOE-ε4 carrier status was significantly associated with the dementia risk. APOE-ε4 carrier status was also associated with the dementia risk. After adjustments for Mediterranean-like diet score and physical activity (Model 2), the interaction remained significant. Significant covariates were APOE-ε4 carrier status, age, T2D, and history of head trauma as risk factors and living in Montpellier as protective factor (Figure 3). Multiple imputations (Model 3) did not change these results showing that the risk of dementia was higher in APOE-ε4 carriers who consumed afternoon snacks with high GL value. To quantify this association, we stratified by APOE-ε4 (Figure S1, S2 in supporting information). In APOE-ε4 carriers, hazard ratio for a 10-point increase in the GL value per day was 2.06 [1.07–4.0]. Finally, in categorical analyses the interaction between the higher tercile of the afternoon-snack GL and APOE-ε4 carrier status was significantly associated with the dementia risk (Table S3 in supporting information). Kaplan-Meyer survival curves clearly illustrated it (Figure S3 in supporting information).

3.2 Sensitivity analyses

By estimating the GL on the basis of the FFQ results, we hypothesized that participants consumed standard serving sizes, leading to potential measurement errors. To evaluate this potential bias, we ran a sensitivity analysis in the Bordeaux subsample using the GL values estimated from the 24-hour dietary recall (Table 3). Proportional hazards models confirmed that the interaction between

afternoon-snack GL and APOE-ε4 carrier status was associated with dementia. Hazard ratios estimated from the 24-hour dietary recall were comparable to those calculated using the FFQ data. These analyses validated our results obtained with the GL values estimated from the FFQ. Moreover, results were not modified by excluding participants with T2D from the analyses (Table S4 in supporting information). Finally, we showed that the interaction between afternoon-snack GL and APOE-ε4 carrier status was significantly associated with the risk of AD by excluding participants with incident mixed and vascular dementia (Table S5 in supporting information).

4. Discussion

In this 12-year follow-up study, we found that higher afternoon-snack GL was associated with an increased risk of dementia and AD in APOE-ε4 carriers using two methods for GL evaluation. This result was independent of energy intake, Mediterranean-like diet, physical activity, and remained significant after exclusion of participants with T2D. The daily GL and GL values of breakfast, lunch, and dinner were not associated with the risk of dementia and AD.

Few previous studies have explored the association between refined carbohydrate intake and dementia or AD. In a cross-sectional analysis, sugar-sweetened beverages were associated with several markers of preclinical AD, such as low total brain volume, and poor Immediate and Delayed Logical Memory scores [39]. Similarly, in another study (n = 208 elderly participants), diet with high GL was associated with poor cognitive performance [12]. The only study on the association between GL and AD did not find any significant association [15]. As in our study, the authors tested the daily GL, but not GL by meal. They did not check for an interaction with APOE-ε4 and had a shorter follow-up (6.3 years). In the Framingham Heart Study (10-year follow-up) no association was found between sugar-sweetened beverages and dementia [40]. Conversely, in the Cardiovascular Risk Factors, Aging and Dementia study, sugar intake reduction (self-reported) in midlife was associated with lower dementia risk over 16.8 years [13].Other studies reported differences according to the APOE-ε4

carrier status. Specifically, the association between T2D and AD was stronger among APOE-ε4 carriers (3.7 times higher) [41].In APOE-ε4 carriers, high midlife glycemia was associated with more serious AD neuropathology [42].Conversely, Schrijvers et al. did not find any significant effect of the interaction between APOE-ε4 carriers and insulin metabolism on AD risk [43].

The statistical interaction between APOE-ε4 carrier and afternoon snack GL on the risk of dementia could be explained in three ways. First, afternoon snacks with high GL could induce oxidative stress, a favorable environment for insulin resistance. Afternoon snacks tend to have high GL because they are usually richer in refined carbohydrates, especially sweets, cereal bars, biscuits, and sodas [4] (Table S6, Figure S4 in supporting information). Snacks are digested more rapidly than full meals because of their lower content in fat and fiber. Thus, post-prandial glycemia quickly increases and induces a high peak in insulin secretion. This chronically repeated high and transitory insulin peaks could promote insulin resistance through oxidative stress and inflammation [44,45] (glucose toxicity hypothesis). Second, APOE-ε4 carriers are more likely to develop insulin resistance. As APOE-ε4 carriers have lower antioxidant activity than APOE-ε4 non-carriers [46], they are less resistant to oxidative stress. Evidence from several studies suggests that APOE-ε4 carriers are less sensitive to insulin. Animal experiments provided a molecular explanation of this observation. In mice that express human APOE-ε4, APOE4 impairs insulin signaling in the cortex, and the hippocampus in an age dependent manner [16]. Moreover, in these mice, the transcription factor peroxisome proliferator-activated receptor gamma, which increases insulin sensitivity, is downregulated [47,48], and glucose metabolism in the brain is decreased. The authors found that this lower glucose metabolism was caused by impaired glucose uptake, glycolytic activity, and mitochondrial respiration. These results are in agreement with epidemiological studies showing that APOE-ε4 carriers have lower brain glucose metabolism (measured by 18F-fluorodeoxyglucose positron-emission tomography) [49,50].Third, the association between insulin resistance and dementia risk is stronger in APOE-ε4 carriers. In the Uppsala Longitudinal Study of Adult Men, high fasting serum insulin and homeostasis model assessment-insulin resistance (HOMAIR) index were associated with

dementia or cognitive impairment over 32 years [51].The association was stronger in APOE-ε4 carriers. We could hypothesize that high intake of refined carbohydrates at afternoon-snack time induces insulin resistance that in turn promotes dementia development. Alternatively, perhaps APOE-ε4 carriers spontaneously consume more refined carbohydrates to compensate for the lower glucose metabolism induced by APOE4. However, in our sample carbohydrate-based food groups were not different between APOE-ε4 carriers and non-carriers (data not shown).

On the other hand, the estimated GL values for breakfast, lunch, and dinner might not reflect the real GL values resulting from the digestion of all food together (i.e., carbohydrates with vegetables, meat, fish, and fat). During meals, carbohydrates are rarely ingested alone, and their degradation and absorption rates during digestion are modified by the other macronutrients. For example, adding fat and/or protein components to a high glycemic index meal decreases the glycemic response [52]. Dietary fibers have a similar effect [53]. The order of food macronutrient intake also changes the glycemic and insulinemic responses. Indeed, higher postprandial glycemic and insulinemic responses are observed when high glycemic index carbohydrates (e.g., rice) are eaten first and then vegetables and meat compared to eating all these foods together [54].

The major strengths of our study are the prospective population-based design, the large number of participants, and the long follow-up period. Data from the 24-hour dietary recall (Bordeaux subsample) validated the results obtained with the FFQ. Moreover, we adjusted for numerous confounding factors. Specifically, our results are independent from energy intake, BMI, diet quality, physical activity, T2D, and also from a possible protective effect of Mediterranean

lifestyle (living in the Montpellier center). However, our study presents some limitations. First, we did not repeat the FFQ during the follow-up. Hence, we could not determine the participants' exposure duration to the actual diet and we do not know whether participants changed their dietary habits during the follow-up. Second, the dietary habits, assessed 12 years ago, could have already reflected changes due to the first symptoms of dementia pathology (protopathic bias). This might have

overestimated the association between afternoon-snack GL and dementia risk in APOE-ε4 carriers. Third, we did not have access to fasting serum insulin data to calculate the HOMA-IR index and to test whether there is an interaction between APOE-ε4 carriers and insulin resistance. Thus, we could not verify whether insulin resistance promotes dementia.

In our prospective cohort study, afternoon snacks rich in refined carbohydrates were associated with dementia risk in APOE-ε4 carriers. These results pave the way to new prevention strategies. However, large-scale studies in different populations and using a homogeneous methodology are required to replicate this observation. Moreover, the statistical interaction between APOE-ε4 status and refined carbohydrate-rich diet should be assessed in future studies. More investigations are needed to explain the mechanisms underlying the role of refined carbohydrate intake, glycemic response, and APOE-ε4 in dementia pathophysiology.

Research in Context

1. Systematic review: We searched for relevant literature using online databases PubMed. We noted the scarcity of published studies dealing with the association between “dementia” [Mesh] or “cognitive dysfunction” [Mesh] and “sugar(s)”, “carbohydrate(s)”, “glyc(a)emic index” or “glyc(a)emic load”. We observed that most of these studies were cross-sectional and/or had a small sample size.
2. Interpretation: Our findings indicate an association between afternoon-snack with a high refined-carbohydrate diet and the risk of dementia in carriers of Apolipoprotein ε4 allele.
3. Future directions: Prospective studies are required to confirm our results. Experimental studies are needed to further explore the relationship between refined carbohydrate diet, glycemic response and apolipoprotein E4 in the pathophysiology leading to dementia.

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Conflicts of interest

The authors have no conflicts of interest to report.

References

[1] World Health Organization. Dementia. WHO 2019. https://www.who.int/news-room/fact-sheets/detail/dementia (accessed June 11, 2019).

[2] Scarmeas N, Anastasiou CA, Yannakoulia M. Nutrition and prevention of cognitive impairment. The Lancet Neurology 2018;17:1006–15. https://doi.org/10.1016/S1474-4422(18)30338-7.

[3] Gross LS, Li L, Ford ES, Liu S. Increased consumption of refined carbohydrates and the epidemic of type 2 diabetes in the United States: an ecologic assessment. Am J Clin Nutr 2004;79:774–9. https://doi.org/10.1093/ajcn/79.5.774.

[4] Bellisle F, Dalix AM, Mennen L, Galan P, Hercberg S, de Castro JM, et al. Contribution of snacks and meals in the diet of French adults: a diet-diary study. Physiol Behav 2003;79:183–9.

[5] Cao D, Lu H, Lewis TL, Li L. Intake of sucrose-sweetened water induces insulin resistance and exacerbates memory deficits and amyloidosis in a transgenic mouse model of Alzheimer disease. J Biol Chem 2007;282:36275–82. https://doi.org/10.1074/jbc.M703561200.

[6] Orr ME, Salinas A, Buffenstein R, Oddo S. Mammalian target of rapamycin hyperactivity mediates the detrimental effects of a high sucrose diet on Alzheimer's disease pathology. Neurobiol Aging 2014;35:1233–42. https://doi.org/10.1016/j.neurobiolaging.2013.12.006.

[7] Arnold SE, Arvanitakis Z, Macauley-Rambach SL, Koenig AM, Wang H-Y, Ahima RS, et al. Brain insulin resistance in type 2 diabetes and Alzheimer disease: concepts and conundrums. Nat Rev Neurol 2018;14:168–81. https://doi.org/10.1038/nrneurol.2017.185.

[8] Philippou E, Pot GK, Heraclides A, Richards M, Bendayan R. Dietary glycaemic index and cognitive function: prospective associations in adults of the 1946 British birth cohort. Public Health Nutrition 2019;22:1415–24. https://doi.org/10.1017/S136898001800352X.

[9] Gilsenan MB, de Bruin EA, Dye L. The influence of carbohydrate on cognitive performance: a critical evaluation from the perspective of glycaemic load. Br J Nutr 2009;101:941–9. https://doi.org/10.1017/S0007114508199019.

[10] Taylor MK, Sullivan DK, Swerdlow RH, Vidoni ED, Morris JK, Mahnken JD, et al. A high-glycemic diet is associated with cerebral amyloid burden in cognitively normal older adults. Am J Clin Nutr 2017;106:1463–70. https://doi.org/10.3945/ajcn.117.162263.

[11] Staubo SC, Aakre JA, Vemuri P, Syrjanen JA, Mielke MM, Geda YE, et al. Mediterranean diet, micronutrients and macronutrients, and MRI measures of cortical thickness. Alzheimer's & Dementia 2017;13:168–77. https://doi.org/10.1016/j.jalz.2016.06.2359.

[12] Power SE, O'Connor EM, Ross RP, Stanton C, O'Toole PW, Fitzgerald GF, et al. Dietary glycaemic load associated with cognitive performance in elderly subjects. Eur J Nutr 2015;54:557–68. https://doi.org/10.1007/s00394-014-0737-5.

[13] Sindi S, Kåreholt I, Eskelinen M, Hooshmand B, Lehtisalo J, Soininen H, et al. Healthy Dietary Changes in Midlife Are Associated with Reduced Dementia Risk Later in Life. Nutrients 2018;10:1649. https://doi.org/10.3390/nu10111649.

[14] Seetharaman S, Andel R, McEvoy C, Dahl Aslan AK, Finkel D, Pedersen NL. Blood Glucose, Diet-Based Glycemic Load and Cognitive Aging Among Dementia-Free Older Adults. J Gerontol A Biol Sci Med Sci 2015;70:471–9. https://doi.org/10.1093/gerona/glu135.

[15] Luchsinger JA, Tang MX, Mayeux R. Glycemic load and risk of Alzheimer's disease. J Nutr Health Aging 2007;11:238–41.

[16] Zhao N, Liu C-C, Van Ingelgom AJ, Martens YA, Linares C, Knight JA, et al. Apolipoprotein E4 Impairs Neuronal Insulin Signaling by Trapping Insulin Receptor in the Endosomes. Neuron 2017;96:115-129.e5. https://doi.org/10.1016/j.neuron.2017.09.003.

[17] 3C Study Group. Vascular factors and risk of dementia: design of the Three-City Study and baseline characteristics of the study population. Neuroepidemiology 2003;22:316–25. https://doi.org/10.1159/000072920.

[18] Samieri C, Jutand M-A, Féart C, Capuron L, Letenneur L, Barberger-Gateau P. Dietary patterns derived by hybrid clustering method in older people: association with cognition, mood, and self-rated health. J Am Diet Assoc 2008;108:1461–71. https://doi.org/10.1016/j.jada.2008.06.437.

[19] Féart C, Jutand MA, Larrieu S, Letenneur L, Delcourt C, Combe N, et al. Energy, macronutrient and fatty acid intake of French elderly community dwellers and association with socio-demographic characteristics: data from the Bordeaux sample of the Three-City Study. Br J Nutr 2007;98:1046–57. https://doi.org/10.1017/S0007114507756520.

[20] Foster-Powell K, Holt SHA, Brand-Miller JC. International table of glycemic index and glycemic load values: 2002. Am J Clin Nutr 2002;76:5–56. https://doi.org/10.1093/ajcn/76.1.5.

[21] Salmerón J, Manson JE, Stampfer MJ, Colditz GA, Wing AL, Willett WC. Dietary fiber, glycemic load, and risk of non-insulin-dependent diabetes mellitus in women. JAMA 1997;277:472–7.

[22] Monro JA, Shaw M. Glycemic impact, glycemic glucose equivalents, glycemic index, and glycemic load: definitions, distinctions, and implications. Am J Clin Nutr 2008;87:237S-243S. https://doi.org/10.1093/ajcn/87.1.237S.

[23] van Bakel MME, Kaaks R, Feskens EJM, Rohrmann S, Welch AA, Pala V, et al. Dietary glycaemic index and glycaemic load in the European Prospective Investigation into Cancer and Nutrition. Eur J Clin Nutr 2009;63:S188–205. https://doi.org/10.1038/ejcn.2009.81.

[24] Trichopoulou A, Costacou T, Bamia C, Trichopoulos D. Adherence to a Mediterranean Diet and Survival in a Greek Population. New England Journal of Medicine 2003;348:2599–608. https://doi.org/10.1056/NEJMoa025039.

[25] Féart C, Samieri C, Rondeau V, Amieva H, Portet F, Dartigues J-F, et al. Adherence to a Mediterranean diet, cognitive decline, and risk of dementia. JAMA 2009;302:638–48. https://doi.org/10.1001/jama.2009.1146.

[26] American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders, 4th Edition, Text Revision (DSM-IV-TR). American Psychiatric Association; 2000.

[27] McKhann G, Drachman D, Folstein M, Katzman R, Price D, Stadlan EM. Clinical diagnosis of Alzheimer's disease: report of the NINCDS-ADRDA Work Group under the auspices of Department of Health and Human Services Task Force on Alzheimer's Disease. Neurology 1984;34:939–44. https://doi.org/10.1212/wnl.34.7.939.

[28] Román GC, Tatemichi TK, Erkinjuntti T, Cummings JL, Masdeu JC, Garcia JH, et al. Vascular dementia: diagnostic criteria for research studies. Report of the NINDS-AIREN International Workshop. Neurology 1993;43:250–60. https://doi.org/10.1212/wnl.43.2.250.

[29] Reitan RM. Validity of the Trail Making Test as an Indicator of Organic Brain Damage. Percept Mot Skills 1958;8:271–6. https://doi.org/10.2466/pms.1958.8.3.271.

[30] Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189–98.

[31] Brindel P, Hanon O, Dartigues J-F, Ritchie K, Lacombe J-M, Ducimetière P, et al. Prevalence, awareness, treatment, and control of hypertension in the elderly: the Three City study. J Hypertens 2006;24:51–8.

[32] Dufouil C, Richard F, Fiévet N, Dartigues JF, Ritchie K, Tzourio C, et al. APOE genotype, cholesterol level, lipid-lowering treatment, and dementia: the Three-City Study. Neurology 2005;64:1531–8. https://doi.org/10.1212/01.WNL.0000160114.42643.31.

[33] Radloff LS. The CES-D Scale: A Self-Report Depression Scale for Research in the General Population. Applied Psychological Measurement 1977;1:385–401. https://doi.org/10.1177/014662167700100306.

[34] Fuhrer R, Rouillon F. La version française de l'échelle CES-D (Center for Epidemiologic Studies-Depression Scale). Description et traduction de l'échelle d'autoévaluation. European Psychiatry 1989;4:163–6.

[35] Letois F, Mura T, Scali J, Gutierrez L-A, Féart C, Berr C. Nutrition and mortality in the elderly over 10 years of follow-up: the Three-City study. Br J Nutr 2016;116:882–9. https://doi.org/10.1017/S000711451600266X.

[36] Norton S, Matthews FE, Barnes DE, Yaffe K, Brayne C. Potential for primary prevention of Alzheimer's disease: an analysis of population-based data. Lancet Neurol 2014;13:788–94. https://doi.org/10.1016/S1474-4422(14)70136-X.

[37] Buuren S van. Flexible Imputation of Missing Data, Second Edition. Chapman and Hall/CRC; 2018. https://doi.org/10.1201/9780429492259.

[38] Shah AD, Bartlett JW, Carpenter J, Nicholas O, Hemingway H. Comparison of random forest and parametric imputation models for imputing missing data using MICE: a CALIBER study. Am J Epidemiol 2014;179:764–74. https://doi.org/10.1093/aje/kwt312.

[39] Pase MP, Himali JJ, Jacques PF, DeCarli C, Satizabal CL, Aparicio H, et al. Sugary beverage intake and preclinical Alzheimer's disease in the community. Alzheimers Dement 2017;13:955–64. https://doi.org/10.1016/j.jalz.2017.01.024.

[40] Pase MP, Himali JJ, Beiser AS, Aparicio HJ, Satizabal CL, Vasan RS, et al. Sugar- and Artificially Sweetened Beverages and the Risks of Incident Stroke and Dementia: A Prospective Cohort Study. Stroke 2017;48:1139–46. https://doi.org/10.1161/STROKEAHA.116.016027.

[41] Peila R, Rodriguez BL, Launer LJ. Type 2 Diabetes, APOE Gene, and the Risk for Dementia and Related Pathologies: The Honolulu-Asia Aging Study. Diabetes 2002;51:1256–62. https://doi.org/10.2337/diabetes.51.4.1256.

[42] Bangen KJ, Himali JJ, Beiser AS, Nation DA, Libon DJ, Fox CS, et al. Interaction Between Midlife Blood Glucose and APOE Genotype Predicts Later Alzheimer's Disease Pathology. J Alzheimers Dis 2016;53:1553–62. https://doi.org/10.3233/JAD-160163.

[43] Schrijvers EMC, Witteman JCM, Sijbrands EJG, Hofman A, Koudstaal PJ, Breteler MMB. Insulin metabolism and the risk of Alzheimer disease. Neurology 2010;75:1982–7. https://doi.org/10.1212/WNL.0b013e3181ffe4f6.

[44] Butterfield DA, Di Domenico F, Barone E. Elevated Risk of Type 2 Diabetes for Development of Alzheimer Disease: a Key Role for Oxidative Stress in Brain. Biochim Biophys Acta 2014;1842:1693–706. https://doi.org/10.1016/j.bbadis.2014.06.010.

[45] Nolan CJ, Ruderman NB, Kahn SE, Pedersen O, Prentki M. Insulin resistance as a physiological defense against metabolic stress: implications for the management of subsets of type 2 diabetes. Diabetes 2015;64:673–86. https://doi.org/10.2337/db14-0694.

[46] Jofre-Monseny L, Minihane A-M, Rimbach G. Impact of apoE genotype on oxidative stress, inflammation and disease risk. Mol Nutr Food Res 2008;52:131–45. https://doi.org/10.1002/mnfr.200700322.

[47] Keeney JT-R, Ibrahimi S, Zhao L. Human ApoE Isoforms Differentially Modulate Glucose and Amyloid Metabolic Pathways in Female Brain: Evidence of the Mechanism of Neuroprotection by ApoE2 and Implications for Alzheimer's Disease Prevention and Early Intervention. J Alzheimers Dis 2015;48:411–24. https://doi.org/10.3233/JAD-150348.

[48] Wu L, Zhang X, Zhao L. Human ApoE Isoforms Differentially Modulate Brain Glucose and Ketone Body Metabolism: Implications for Alzheimer's Disease Risk Reduction and Early Intervention. J Neurosci 2018;38:6665–81. https://doi.org/10.1523/JNEUROSCI.2262-17.2018.

[49] Reiman EM, Chen K, Alexander GE, Caselli RJ, Bandy D, Osborne D, et al. Correlations between apolipoprotein E epsilon4 gene dose and brain-imaging measurements of regional hypometabolism. Proc Natl Acad Sci USA 2005;102:8299–302. https://doi.org/10.1073/pnas.0500579102.

[50] Rimajova M, Lenzo NP, Wu J-S, Bates KA, Campbell A, Dhaliwal SS, et al. Fluoro-2-deoxy-D-glucose (FDG)-PET in APOEepsilon4 carriers in the Australian population. J Alzheimers Dis 2008;13:137–46.

[51] Rönnemaa E, Zethelius B, Sundelöf J, Sundström J, Degerman-Gunnarsson M, Berne C, et al. Impaired insulin secretion increases the risk of Alzheimer disease. Neurology 2008;71:1065–71. https://doi.org/10.1212/01.wnl.0000310646.32212.3a.

[52] Hätönen KA, Virtamo J, Eriksson JG, Sinkko HK, Sundvall JE, Valsta LM. Protein and fat modify the glycaemic and insulinaemic responses to a mashed potato-based meal. Br J Nutr 2011;106:248–53. https://doi.org/10.1017/S0007114511000080.

[53] Post RE, Mainous AG, King DE, Simpson KN. Dietary fiber for the treatment of type 2 diabetes mellitus: a meta-analysis. J Am Board Fam Med 2012;25:16–23. https://doi.org/10.3122/jabfm.2012.01.110148.

[54] Sun L, Goh HJ, Govindharajulu P, Leow MK-S, Henry CJ. Postprandial glucose, insulin and incretin responses differ by test meal macronutrient ingestion sequence (PATTERN study). Clin Nutr 2019. https://doi.org/10.1016/j.clnu.2019.04.001.

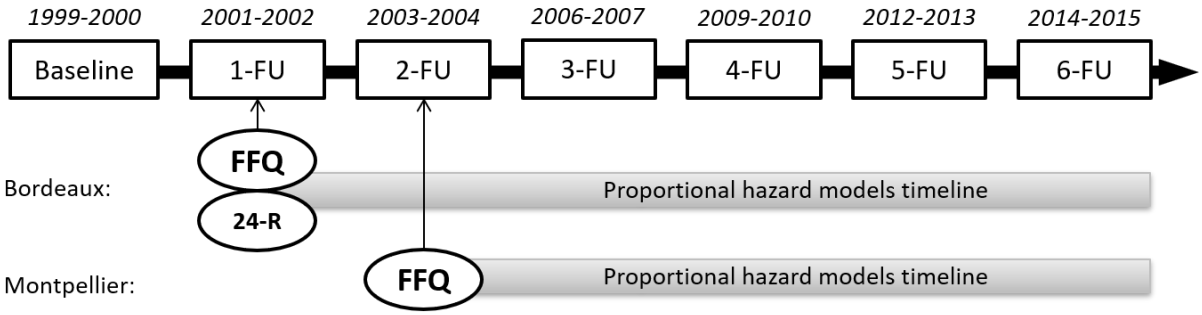

Figure 1. Time frame of the Three-City Study at the Bordeaux and Montpellier centres. Diagnosis of dementia is made at each follow-up visit (FU). The food frequency questionnaire (FFQ) was completed by participants at 1-FU in Bordeaux and at 2-FU in Montpellier. The 24-h dietary recall (24-R) was only completed by participants at 1-FU in Bordeaux.

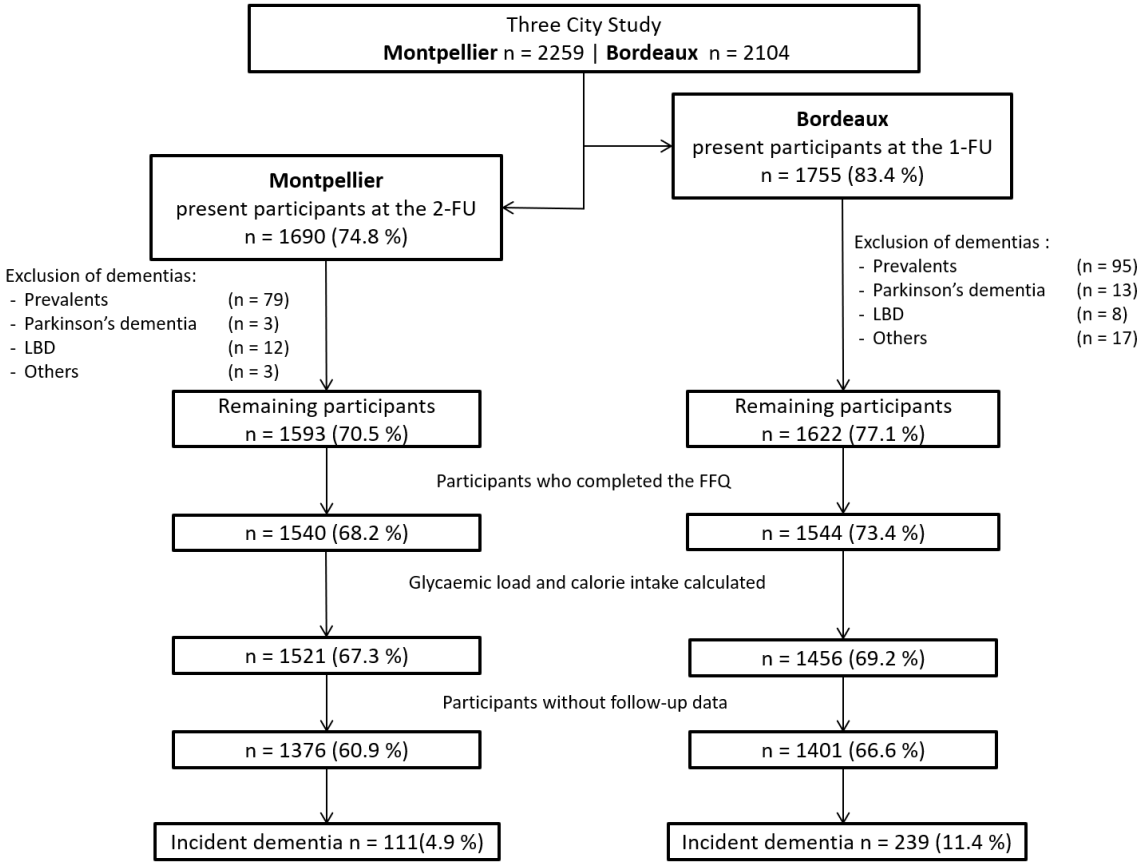

Figure 2. Flow chart of the study sample from the Bordeaux and Montpellier centres of the Three-City Study. Abbreviations: FFQ, Food frequency questionnaire; FU, follow-up; LBD, Lewy Body Dementia.

Table 1 Characteristics of the study population

Characteristics	Mean (SD) or n (%)	Range	Missing values (%)
Montpellier centre	1376 (49.6)		
Age (years)	75.9 (4.9)	68 - 96	
Women	1696 (61.1)		
Education level			
No school	737 (26.5)		
Primary school	784 (28.2)		
High school	635 (22.9)		
Graduated	614 (22.1)		
MMSE (IQR)	28 (27-29)	19 - 30	
APOE4 carriers	482 (17.5)		5.3
BMI (kg/m²)	25.7 (3.9)	13.59 - 45.18	
Type 2 diabetes	281 (10.1)		
Hypertension	1676 (60.4)		
Cardiovascular history	307 (11.1)		
History of stroke	116 (4.2)		
Hypercholesterolemia	1536 (55.3)		3.1
History of head trauma	176 (6.34)		
Depressive symptomatology*	220 (7.92)		
Good subjective health	2657 (95.7)		
Tobacco use (current or past)	1066 (38.4)		
Mediterranean diet-like	4.7 (1.6)	0 - 9	6.7
Physical activity	894 (32.19)		14.3
Glycaemic load (/day)	108.3 (34.3)	10.6 - 323.6	
Energy intake (kJ/day)	4851 (1537)	1311 - 15925	

*evaluated with the Center for Epidemiological Studies-Depression scale. Abbreviations: *APOE-ε4*, apolipoprotein E ε4 allele; BMI, body mass index; MMSE, Mini Mental State Examination; SD, standard deviation.

Table 2. Association between glycaemic load and risk of dementia over 11.4 ± 2 years of follow-up.

	Model 1 n = 2,572		Model 2 n = 2,145		Model 3 n = 2,777	
Exposure	HR*(CI)	*P* value	HR*(CI)	*P* value	HR*(CI)	*P* value
Daily						
GL	0.99 (0.91-1.08)	.86	1.00 (0.91-1.11)	.97	1.01 (0.94-1.10)	.73
APOE-ε4	1.12 (0.44-2.90)	.81	1.14 (0.38-3.40)	.82	1.32 (0.53-3.29)	.56
GL x *APOE*-ε4	1.05 (0.97-1.14)	.21	1.05 (0.96-1.16)	.28	1.04 (0.96-1.13)	.32
Breakfast						
GL	0.97 (0.81-1.15)	.72	0.99 (0.80-1.21)	.90	1.03 (0.87-1.21)	.75
APOE-ε4	1.46 (0.79-2.70)	.23	1.80 (0.89-3.64)	.10	1.58 (0.88-2.85)	.12
GL x *APOE*-ε4	1.13 (0.92-1.40)	.25	1.05 (0.82-1.34)	.72	1.10 (0.90-1.35)	.34
Lunch						
GL	0.91 (0.72-1.15)	.43	0.91 (0.69-1.21)	.53	0.99 (0.80-1.24)	.96
APOE-ε4	2.07 (0.82-5.2)	.12	2.65 (0.90-7.84)	.078	2.16 (0.88-5.29)	.093
CG x *APOE*-ε4	0.99 (0.76-1.29)	.96	0.92 (0.67-1.27)	.62	0.98 (0.76-1.27)	.91
Afternoon snack						
GL	1.18 (0.89-1.55)	.24	1.28 (0.92-1.77)	.14	1.13 (0.87-1.46)	.36
APOE-ε4	1.59 (1.14-2.22)	.007	1.53 (1.04-2.25)	.03	1.65 (1.20-2.28)	.002
GL x *APOE*-ε4	1.31 (1.05-1.63)	**.015**	1.39 (1.09-1.79)	**.009**	1.27 (1.03-1.57)	**.027**
Dinner						
GL	0.92 (0.74-1.13)	.42	0.94 (0.73-1.22)	.65	0.88 (0.72-1.09)	.25
APOE-ε4	2.73 (1.25-5.96)	.012	2.65 (1.03-6.86)	.044	2.84 (1.33-6.08)	.007
GL x *APOE*-ε4	0.91 (0.73-1.14)	.42	0.92 (0.71-1.20)	.56	0.91 (0.73-1.12)	.36

Abbreviations: *APOE*-ε4, Apolipoprotein E ε4 allele; CI, confidence interval; GL, glycaemic load; HR, hazard ratio.

NOTE. Proportional hazard models. Model 1 was adjusted for inclusion centre, age, sex, education level, energy intake, *APOE*-ε4 status, BMI, type 2 diabetes, hypertension, cardiovascular history, history of stroke, hypercholesterolemia, history of head trauma, depressive symptomatology, subjective health, and tobacco. Model 2 included additional adjustments for Mediterranean diet-like score and physical activity. Model 3 is Model 2 with multiple imputations

* HR for a 10-point increase in the GL value per day that is equivalent to eating an additional 30 g of a French baguette at each corresponding meal.

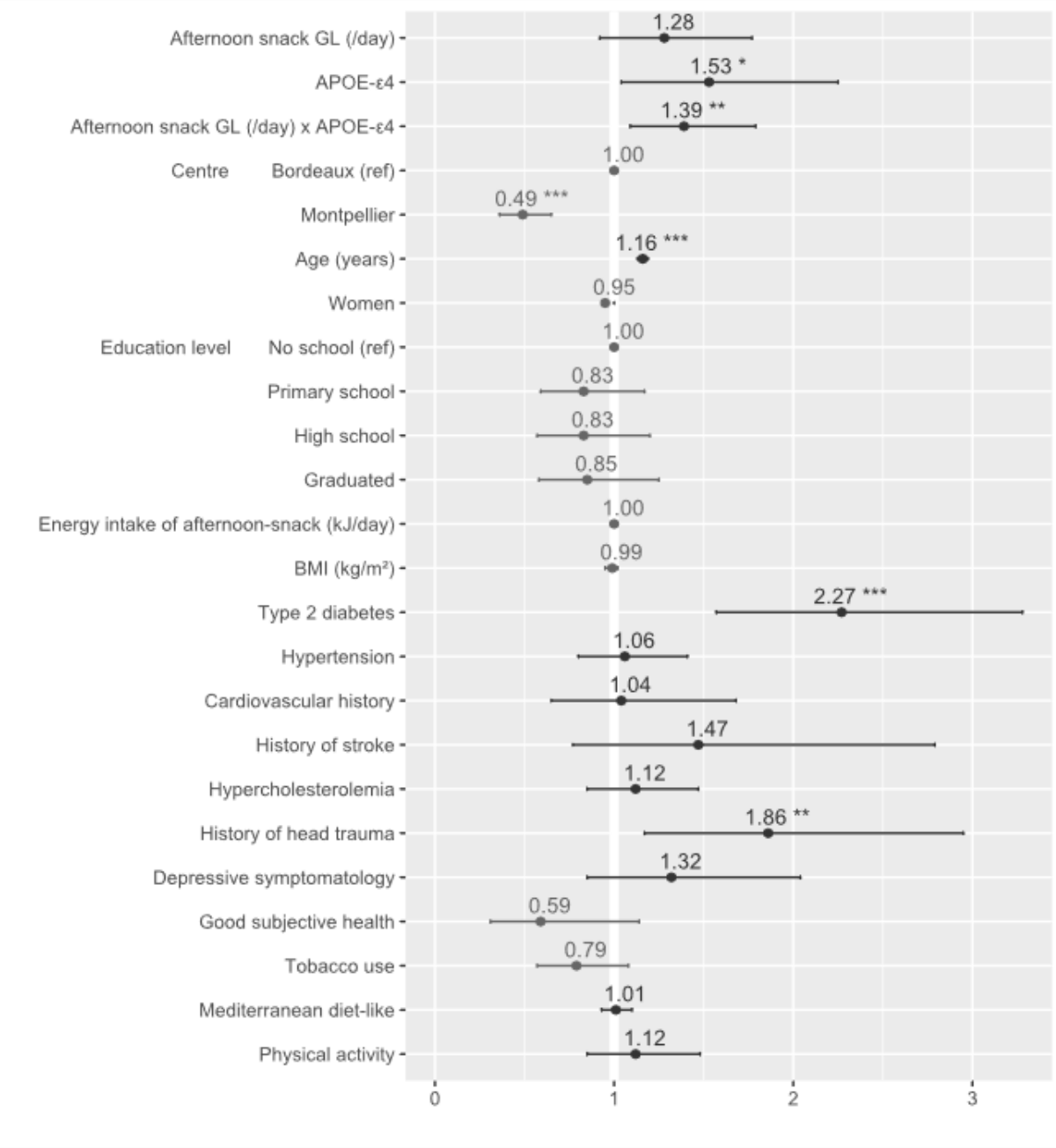

Figure 3. Estimated hazard ratios of all covariates from Model 2 (n = 2,145). The hazard ratio of the afternoon-snack GL is expressed as a 10-point increase of the GL value per day that is equivalent to eating an additional 30 g of French baguette at each corresponding meal. Abbreviations: *APOE*-ε4, apolipoprotein E ε4 allele; BMI, body mass index; GL, glycemic load.* *P* value < .05; ** *P* value < .01; *** *P* value < .001.

Table 3. Association between the glycaemic load, estimated from the 24-h dietary recall interview (Bordeaux centre), and the risk of dementia during 13 years of follow-up.

	Model 1 n = 1,229		Model 2 n = 954	
Exposure	HR*(CI)	*P* value	HR*(CI)	*P* value
Daily				
GL	1.01 (0.96-1.07)	.62	1.01 (0.94-1.07)	.82
APOE-ε4	1.59 (0.58-4.31)	.36	1.45 (0.45-4.65)	.53
GL x *APOE*-ε4	1.00 (0.92-1.10)	.95	1.01 (0.90-1.12)	.93
Breakfast				
GL	1.02 (0.85-1.23)	.85	1.04 (0.84-1.29)	.73
APOE-ε4	1.61 (0.87-2.97)	.13	1.71 (0.82-3.54)	.15
GL x *APOE*-ε4	1.01 (0.82-1.23)	.95	0.95 (0.74-1.22)	.69
Lunch				
GL	1.00 (0.9-1.11)	.94	1.01 (0.90-1.14)	.85
APOE-ε4	2.12 (1.00-4.52)	.052	1.83 (0.74-4.56)	.19
CG x *APOE*-ε4	0.93 (0.78-1.12)	.46	0.95 (0.76-1.18)	.64
Afternoon snack				
GL	1.13 (0.88-1.53)	.44	1.34 (0.84-2.14)	.22
APOE-ε4	1.41 (0.94-2.09)	.094	1.25 (0.78-2.00)	.35
GL x *APOE*-ε4	1.39 (1.01-1.93)	**.045**	1.52 (1.06-2.24)	**.023**
Dinner				
GL	1.02 (0.91-1.14)	.71	0.97 (0.85-1.11)	.65
APOE-ε4	1.79 (0.83-3.86)	.14	1.72 (0.67-4.39)	.26
GL x *APOE*-ε4	0.97 (0.77-1.21)	.77	0.95 (0.72-1.25)	.73

Abbreviations: *APOE*-ε4, Apolipoprotein E ε4 allele; CI, confidence interval; GL, glycaemic load; HR, hazard ratio.

NOTE. Proportional hazard models. Model 1 was adjusted for age, sex, education level, energy intake, *APOE*-ε4, BMI, type 2 diabetes, hypertension, cardiovascular history, history of stroke, hypercholesterolemia, history of head trauma, depressive symptomatology, subjective health, and tobacco. Model 2 included additional adjustments for Mediterranean diet-like score and physical activity.

* HR for a 10-point GL increase per day that is equivalent to eating an additional 30 g of French baguette at each corresponding meal.

Table S1. Extract from the FFQ used at 1-FU (Bordeaux) and 2-FU (Montpellier), translated from French version. FFQ items from the afternoon snack (between lunch and dinner) are presented.

Between lunch and dinner, what do you eat?	**Never** or less than once a month	Number of times per **month**	Number of times per **week**
Bread	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Rusk	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Butter	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Margarine	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Jam (or honey)	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Pastry	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Cereal	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Dry biscuits	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Jam biscuits	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Chocolate biscuits	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Cakes	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Yogurt	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Cheese	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Fruits	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Eggs	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Charcuterie	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Sweets, chocolate, chocolate bars	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Stewed fruit	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Between lunch and dinner, what do you drink?	**Never** or less than once a month	Number of times per **month**	Number of times per **week**
Coffee	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Coffee with milk	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Tea	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Tea with milk	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Chicory	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Hot chocolate	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Milk	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Soup	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Fruit juice	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Soda	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Light soda	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Water	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Wine	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Beer	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍
Strong alcohols	❍	1 ❍ 2 ❍ 3 ❍	1 ❍ 2 ❍ 3 ❍ 4 ❍ 5 ❍ 6 ❍ 7 ❍

Table S2. Characteristics of the study population according to daily glycaemic load tercile (per day)

Characteristics	Mean (SD) or n (%)		
	Lower (<90)	Middle (90 to <115)	Upper (≥115)
Montpellier centre	377 (40.7)	418 (45.2)	581 (62.6)
Age (years)	75.98 (4.9)	75.52 (4.9)	76.28 (4.9)
Women	600 (64.9)	542 (58.7)	554 (59.7)
Education level			
No school	260 (28.1)	245 (26.5)	232 (25.0)
Primary school	267 (28.9)	270 (29.2)	247 (26.6)
High school	203 (22.0)	207 (22.4)	225 (24.3)
Graduated	194 (21.0)	199 (21.5)	221 (23.8)
MMSE	28 (27-29)	28 (27-29)	28 (27-29)
APOE4 carriers	156 (16.9)	172 (18.6)	154 (16.6)
BMI (kg/m²)	26.3 (4.2)	25.81 (4.0)	24.9 (3.4)
Type 2 diabetes	129 (14.0)	84 (9.1)	68 (7.3)
Hypertension	596 (64.4)	555 (60.1)	525 (56.6)
Cardiovascular history	115 (12.4)	103 (11.2)	89 (9.6)
Stroke	41 (4.4)	32 (3.5)	43 (4.6)
Hypercholesterolemia	501 (54.2)	537 (58.1)	498 (53.7)
Head trauma	54 (5.84)	53 (5.7)	69 (7.4)
Depressive symptomatology*	81 (8.76)	59 (6.4)	80 (8.6)
Good subjective health	887 (95.9)	885 (95.8)	885 (95.4)
Tobacco use (current or past)	384 (41.5)	349 (37.8)	333 (35.9)
Mediterranean diet-like	4.14 (1.5)	4.75 (1.6)	5.2 (1.5)
Physical activity	256 (27.7)	295 (31.9)	343 (37.0)
Energy intake (kJ/day)	3533 (686)	4660 (652)	6355 (1464)

*evaluated with the Center for Epidemiological Studies-Depression scale. Abbreviations: *APOE-ε4*, apolipoprotein E ε4 allele; BMI, body mass index; MMSE, Mini Mental State Examination; SD, standard deviation.

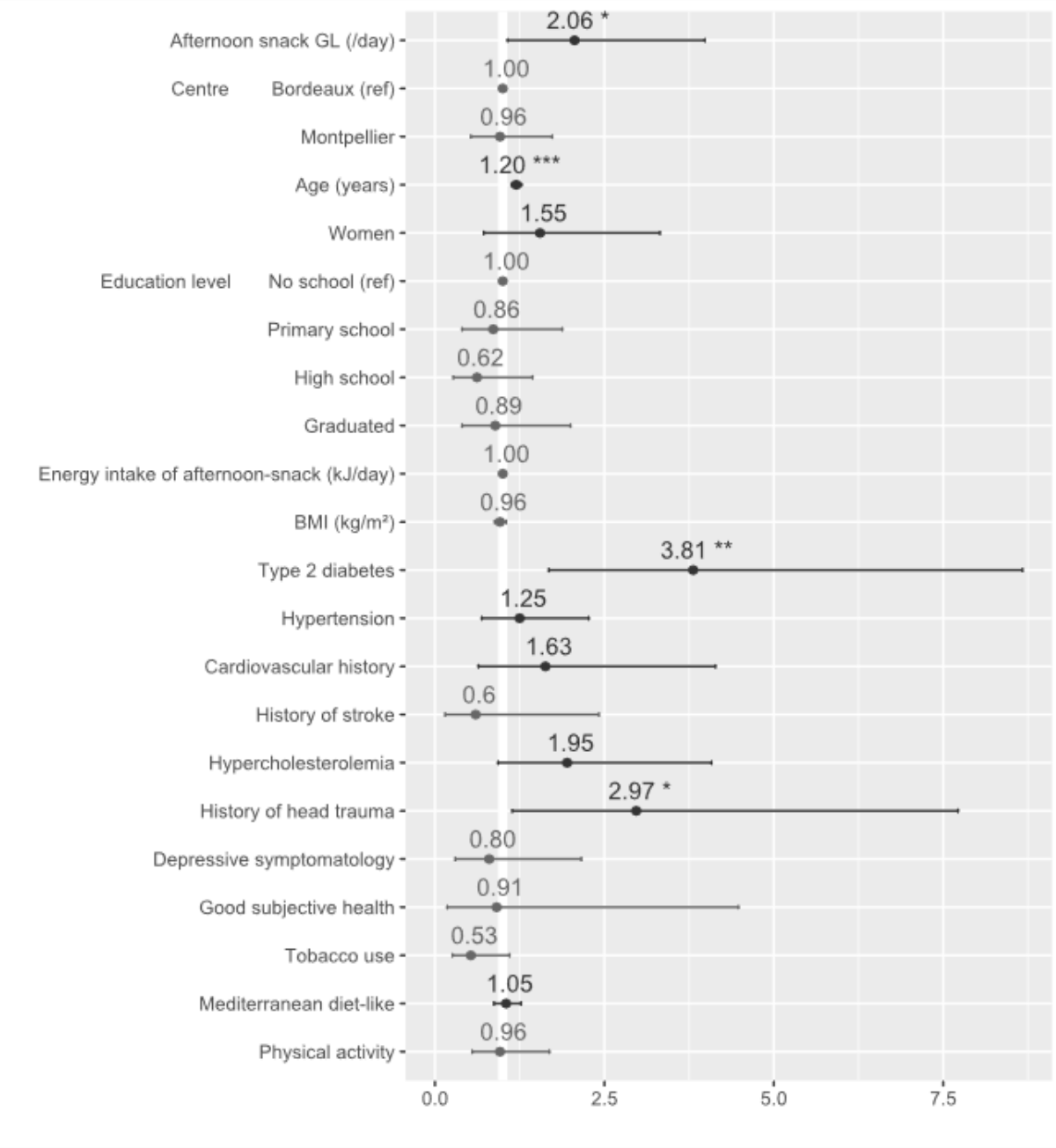

Figure S1. Stratified analysis on participants with *APOE*-ε4 status. Estimated hazard ratios of all covariates from Model 2 (n = 391). The hazard ratio of the afternoon-snack GL is expressed as a 10-point increase of the GL value per day that is equivalent to eating an additional 30 g of French baguette at each corresponding meal. Abbreviations: *APOE*-ε4, apolipoprotein E ε4 allele; BMI, body mass index; GL, glycaemic load. * *P* value < .05; ** *P* value < .01; *** *P* value < .001.

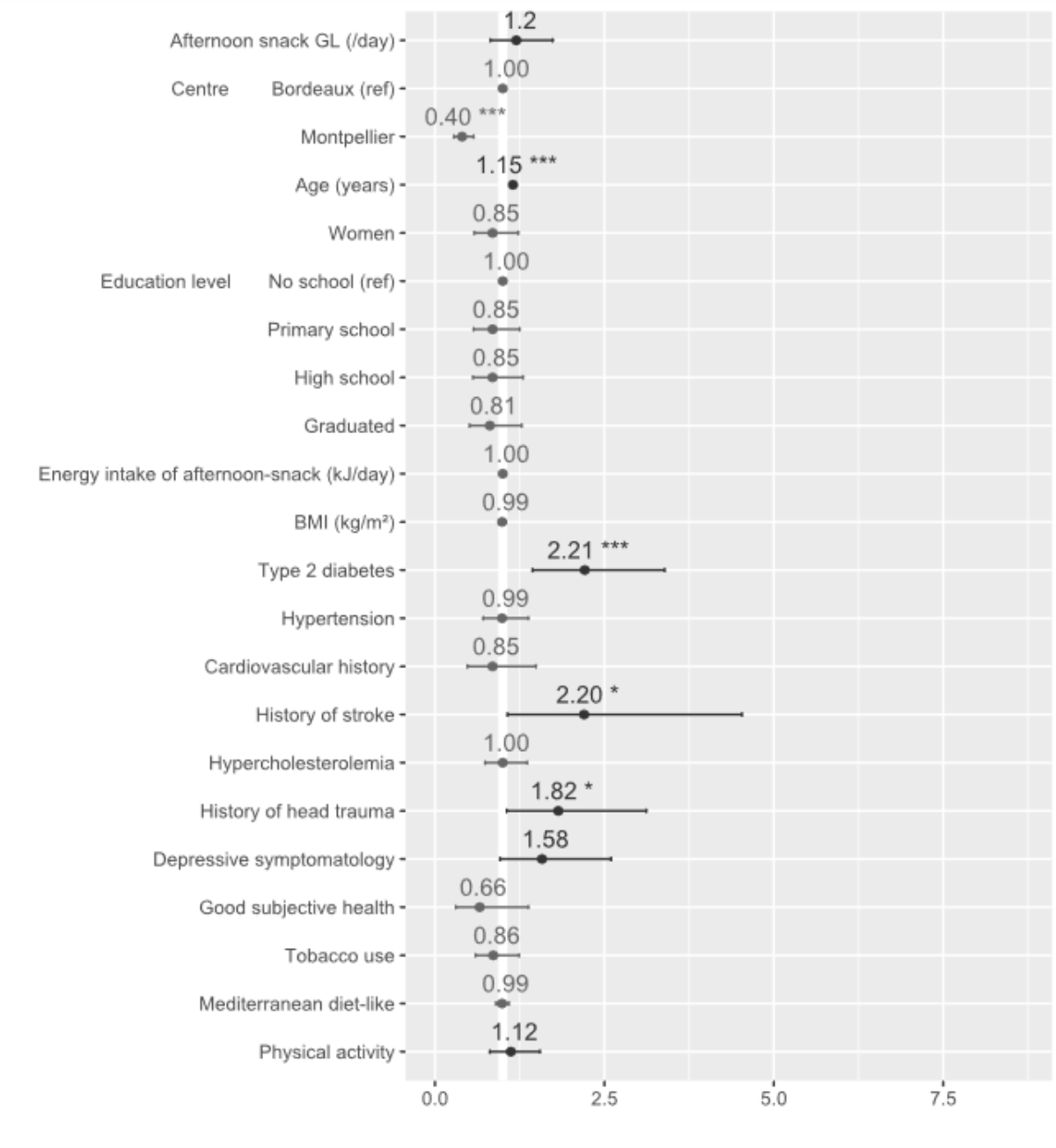

Figure S2. Stratified analysis on participants without *APOE*-ε4 status. Estimated hazard ratios of all covariates from Model 2 (n = 1,754). The hazard ratio of the afternoon-snack GL is expressed as a 10-point increase of the GL value per day that is equivalent to eating an additional 30 g of French baguette at each corresponding meal. Abbreviations: *APOE*-ε4, apolipoprotein E ε4 allele; BMI, body mass index; GL, glycaemic load. * *P* value < .05; ** *P* value < .01; *** *P* value < .001.

Table S3. Association between glycaemic load terciles of each meal and risk of dementia over 11.4 ± 2 years of follow-up. Daily GL terciles was GL<90, 90<GL<115 and GL≥115 per day. Breakfast GL terciles was GL<20, 20<GL<30 and GL≥30 per day. Lunch GL terciles was GL<30, 30<GL<37 and GL≥37 per day. Afternoon-snack GL terciles was GL=0, 0<GL<10 and GL≥10 per day. Dinner GL terciles was GL<29, 29<GL<38 and GL≥38 per day.

	Model 1 n = 2,317		Model 2 n = 1,934	
Exposure	HR*(CI)	*P* value	HR*(CI)	*P* value
Daily				
Lower	(ref)		(ref)	
Middle	1.02 (0.72-1.44)	.932	1.02(0.68-1.54)	.91
Upper	1.23 (0.79-1.91)	.371	1.35(0.8-2.27)	.267
APOE-ε4	2.15 (1.35-3.42)	.001	2.23(1.32-3.76)	.003
Lower x *APOE*-ε4	(ref)		(ref)	
Middle x *APOE*-ε4	0.84 (0.44-1.6)	.593	0.82(0.39-1.72)	.591
Upper x *APOE*-ε4	1.00 (0.53-1.88)	.991	0.95(0.46-1.96)	.884
Breakfast				
Lower	(ref)		(ref)	
Middle	0.94 (0.68-1.31)	.731	1.01(0.69-1.47)	.952
Upper	0.92 (0.6-1.41)	.706	0.93(0.57-1.53)	.777
APOE-ε4	1.56 (0.96-2.51)	.07	1.54(0.88-2.7)	.133
Lower x *APOE*-ε4	(ref)		(ref)	
Middle x *APOE*-ε4	1.55 (0.82-2.92)	.179	1.75 (0.85-3.63)	.129
Upper x *APOE*-ε4	1.35 (0.7-2.61)	.367	1.20 (0.55-2.62)	.647
Lunch				
Lower	(ref)		(ref)	
Middle	0.92 (0.65-1.31)	.655	0.92 (0.61-1.37)	.669
Upper	1.13 (0.73-1.74)	.582	1.15 (0.7-1.91)	.577
APOE-ε4	2.16 (1.39-3.35)	.001	2.19 (1.33-3.63)	.002
Lower x *APOE*-ε4	(ref)		(ref)	
Middle x *APOE*-ε4	0.93 (0.5-1.73)	.826	0.91 (0.45-1.85)	.79
Upper x *APOE*-ε4	0.90 (0.48-1.7)	.75	0.91 (0.43-1.91)	.798

Afternoon snack				
Lower	(ref)		(ref)	
Middle	1.06 (0.76-1.46)	.745	1.06 (0.73-1.52)	.773
Upper	0.99 (0.63-1.58)	.978	0.96 (0.57-1.63)	.881
APOE-ε4	1.42 (0.89-2.25)	.141	1.16 (0.67-2.01)	.598
Lower x *APOE*-ε4	(ref)		(ref)	
Middle x *APOE*-ε4	1.27 (0.65-2.46)	.481	1.73 (0.8-3.74)	.162
Upper x *APOE*-ε4	2.25 (1.21-4.18)	**.01**	3.26(1.57-6.79)	**.002**
Dinner				
Lower	(ref)		(ref)	
Middle	0.95 (0.67-1.35)	.763	1.13 (0.75-1.69)	.568
Upper	0.82 (0.51-1.32)	.42	0.89 (0.51-1.55)	.67
APOE-ε4	2.69 (1.75-4.12)	<.0001	2.77 (1.65-4.64)	<.0001
Lower x *APOE*-ε4	(ref)		(ref)	
Middle x *APOE*-ε4	0.64 (0.33-1.21)	.167	0.59 (0.28-1.25)	.166
Upper x *APOE*-ε4	0.66 (0.36-1.21)	.18	0.68 (0.33-1.4)	.297

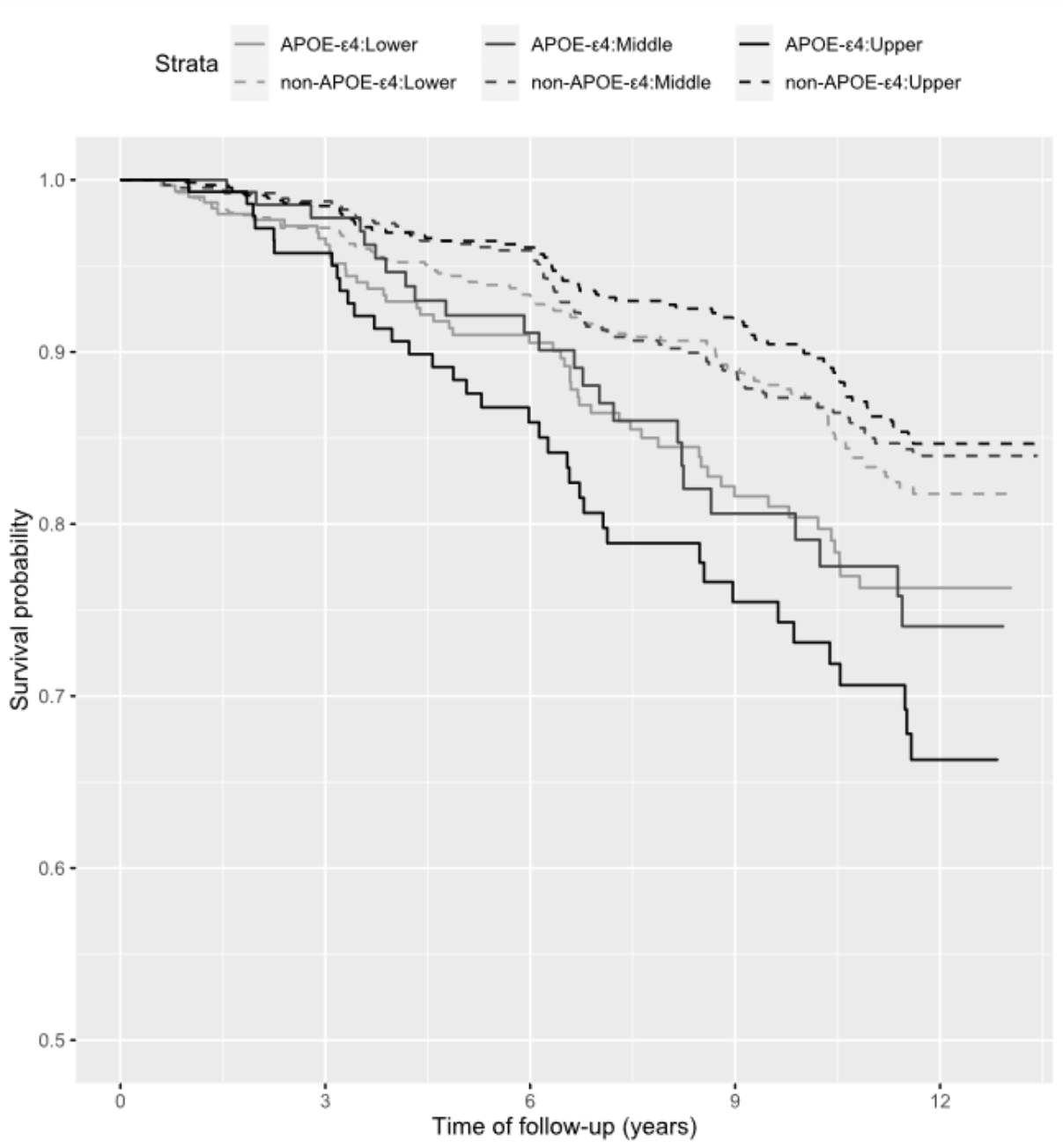

Figure S3. Kaplan-Meier survival curves according to afternoon-snack GL terciles and *APOE*-ε4 carriers status. Time to diagnosis of dementia for *APOE*-ε4 carriers participants (solid line) or non-*APOE*-ε4 carriers participants (dashed line) with GL=0 (light grey), 0<GL<10 (dark grey) or GL≥10 per day (black). Abbreviations: *APOE*-ε4, apolipoprotein E ε4 allele; GL, glycaemic load.

Table S4. Association between glycaemic load and risk of dementia during 11.4 ± 2 years without participants with type 2 diabetes.

	Model 1 n = 2,317		Model 2 n = 1,934	
Exposure	HR*(CI)	*P* value	HR*(CI)	*P* value
Daily				
GL	0.99 (0.90-1.09)	.84	0.99 (0.89-1.10)	.83
APOE-ε4	1.03 (0.37-2.91)	.95	0.89 (0.26-3.03)	.85
GL x *APOE*-ε4	1.07 (0.98-1.16)	.15	1.08 (0.97-1.19)	.17
Breakfast				
GL	1.01 (0.84-1.22)	.93	1.01 (0.81-1.25)	.95
APOE-ε4	1.46 (0.74-2.87)	.27	1.55 (0.70-3.42)	.28
GL x *APOE*-ε4	1.15 (0.92-1.44)	.22	1.1 (0.85-1.44)	.46
Lunch				
GL	0.80 (0.62-1.04)	.091	0.81 (0.60-1.10)	.17
APOE-ε4	2.29 (0.84-6.23)	.11	3.21 (0.97-10.6)	.056
CG x *APOE*-ε4	0.98 (0.74-1.30)	.88	0.87 (0.61-1.23)	.43
Afternoon snack				
GL	1.15 (0.86-1.54)	.35	1.19 (0.84-1.69)	.33
APOE-ε4	1.58(1.09-2.29)	.016	1.43(0.92-2.21)	.113
GL x *APOE*-ε4	1.38 (1.01-1.75)	**.008**	1.47 (1.11-1.93)	**.007**
Dinner				
GL	0.94 (0.75-1.19)	.62	0.96 (0.73-1.26)	.78
APOE-ε4	2.74 (1.17-6.40)	.02	2.29 (0.78-6.78)	.13
GL x *APOE*-ε4	0.93 (0.73-1.17)	.53	0.96 (0.71-1.29)	.80

Abbreviations: *APOE*-ε4, Apolipoprotein E ε4 allele; CI, confidence interval; GL, glycaemic load; HR, hazard ratio.

NOTE. Proportional hazard models. Model 1 was adjusted for inclusion centre, age, sex, education level, energy intake, *APOE*-ε4, BMI, hypertension, cardiovascular history, history of stroke, hypercholesterolemia, history of head trauma, depressive symptomatology, subjective health, and tobacco. Model 2 included additional adjustments for Mediterranean diet-like score and physical activity.

* HR for a 10-point GL increase per day that is equivalent to eating an additional 30 g of French baguette at each corresponding meal.

Table S5. Association between glycaemic load and risk of Alzheimer's disease (exclusion of participants with mixed dementia and vascular dementia) during 11.4 ± 2 years of follow-up.

	Model 1 n = 2,489		Model 2 n = 2,078	
Exposure	HR*(CI)	*P* value	HR*(CI)	*P* value
Daily				
GL	1.02 (0.92-1.12)	.73	1.06 (0.94-1.19)	.33
APOE-ε4	0.86 (0.29-2.56)	.79	0.89 (0.25-3.18)	.86
GL x *APOE*-ε4	1.09 (0.99-1.19)	.072	1.08 (0.97-1.20)	.16
Breakfast				
GL	0.99 (0.80-1.21)	.89	1.03 (0.81-1.30)	.82
APOE-ε4	1.26 (0.62-2.56)	.52	1.59 (0.70-3.62)	.27
GL x *APOE*-ε4	1.24 (0.98-1.56)	.075	1.12 (0.85-1.47)	.43
Lunch				
GL	0.96 (0.73-1.27)	.78	1.07 (0.77-1.49)	.69
APOE-ε4	2.02 (0.69-5.87)	.20	2.68 (0.74-9.63)	.13
CG x *APOE*-ε4	1.03 (0.76-1.39)	.85	0.94 (0.65-1.35)	.72
Afternoon snack				
GL	1.30 (0.95-1.76)	.10	1.41 (0.97-2.04)	.07
APOE-ε4	1.72 (1.16-2.54)	.007	1.60 (1.01-2.52)	.043
GL x *APOE*-ε4	1.32 (1.04-1.68)	**.03**	1.39 (1.05-1.84)	**.02**
Dinner				
GL	0.91 (0.71-1.17)	.45	0.99 (0.73-1.34)	.95
APOE-ε4	2.88 (1.17-7.10)	.02	2.97 (0.98-9.00)	.054
GL x *APOE*-ε4	0.93 (0.72-1.19)	.56	0.91 (0.67-1.24)	.54

Abbreviations: *APOE*-ε4, Apolipoprotein E ε4 allele; CI, confidence interval; GL, glycaemic load; HR, hazard ratio.

NOTE. Proportional hazard models. Model 1 was adjusted for inclusion centre, age, sex, education level, energy intake, *APOE*-ε4, BMI, type 2 diabetes, hypertension, cardiovascular history, history of stroke, hypercholesterolemia, history of head trauma, depressive symptomatology, subjective health, and tobacco. Model 2 included additional adjustments for Mediterranean diet-like score and physical activity.

* HR for a 10-point GL increase per day that is equivalent to eating an additional 30 g of French baguette at each corresponding meal.

Table S6. Number of servings per week for each meal.

Food groups	**Breakfast**	**Lunch**	**Afternoon snack**	**Dinner**
	Mean (standard deviation)			
Cereals, bread	6.2 (3.04)	6.1 (3.04)	0.4 (1.45)	5.6 (2.62)
Starchy foods		4.2 (2.32)		2.6 (2.55)
Meat, poultry		4.5 (3.84)		1.7 (1.88)
Fish and seafood		2.2 (3.05)		0.9 (1.23)
Eggs, charcuterie	0.2 (1.12)	1.6 (3.28)	0.04 (0.39)	1.9 (1.79)
Vegetables, legumes		7.6 (1.12)		3.5 (3.21)
Fruits	1.0 (2.32)	5.1 (3.24)	0.7 (1.76)	4.0 (2.95)
Biscuits, cakes	4.2 (3.84)	1.0 (3.04)	1.5 (2.69)	1.3 (1.94)
Sweets, chocolate,	1.8 (3.05)	0.3 (2.32)	1.2 (2.43)	0.2 (0.86)
Dairy products	1.8 (3.28)	6.3 (3.84)	0.5 (1.55)	7.3 (3.76)
Coffee, tea	5.3 (3.24)	4.1 (3.05)	1.6 (2.71)	0.4 (1.60)

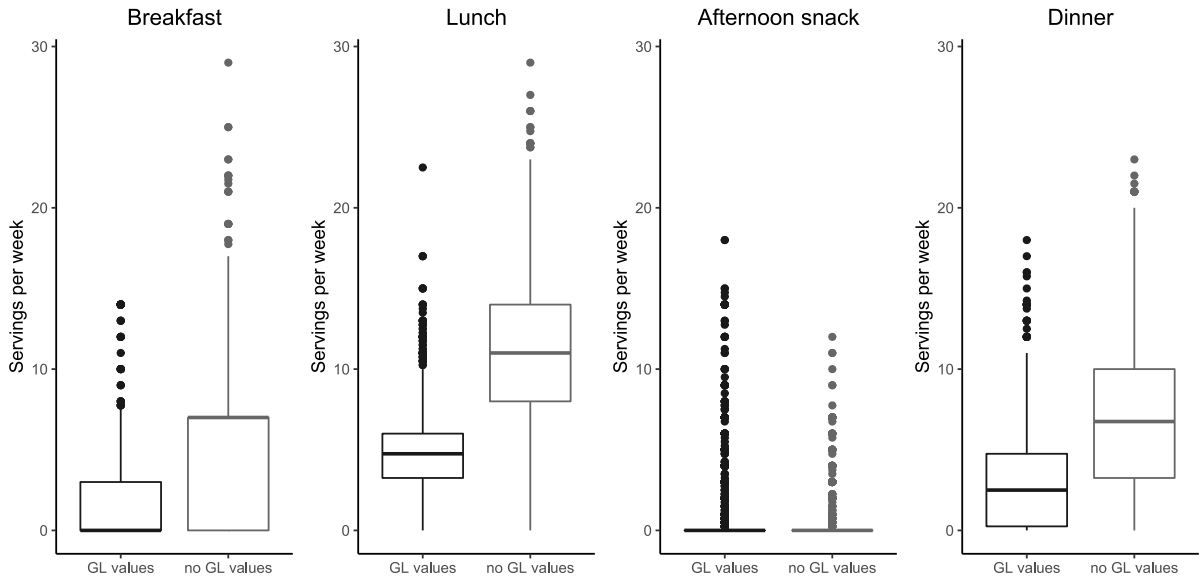

Figure S4. Servings per week of the FFQ items according to their glycaemic load values: no GL value (e.g., meat, fish, fat) and GL values. Abbreviations: FFQ, Food Frequency Questionnaire; GL, glycaemic load.