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Association of dietary fat composition with cognitive performance and brain morphology in cognitively healthy individuals

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Original Article

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Abstract

Background: Dietary lipids (omega-3 polyunsaturated fatty acids (*n-3*) PUFAs) and saturated fatty acids (SFA) seem to play an important role in brain health. (*n-3)* PUFAs have been shown to improve cerebral perfusion and to promote synaptogenesis. In this study, we investigated the relationship between dietary fat composition, cognitive performance and brain morphology in cognitively healthy individuals. *Methods:* A total of 101 cognitively healthy participants (age: 42.3 ± 21.3 years, 62 females) were included in this study. Verbal memory was assessed using the California Verbal Learning Test (CVLT). Intake of (*n-3*) PUFA and SFA was calculated from food-frequency questionnaire-derived data (EPIC-FFQ). Magnetic resonance imaging (MRI) data were obtained (Siemens Trio 3T scanner) and grey matter volumes (GMV) were assessed by voxel-based morphometry (VBM/SPM8). We examined the association of SFA/(*n-3)* PUFA ratio and memory performance as well as GMV using regression models adjusted for age, sex, education, body mass index, apolipoprotein E (APOE) status and alcohol consumption. For VBM data, a multiple regression analysis was performed using the same covariates as mentioned before with intracranial volume as an additional covariate. *Results:* A high SFA/(*n-3)* PUFA ratio was significantly ($p < 0.05$) correlated with poorer verbal memory performance and with lower GMV in areas of the left prefrontal cortex that support memory processes. *Conclusions:* These findings suggest that a diet rich in PUFAs is likely to exert favourable effects on brain morphology in brain areas important for memory and executive functions. This could constitute a possible mechanism for maintaining cognitive health in older age.

Significant outcomes:

- A diet rich in saturated fatty acids (SFA) was associated with poorer memory performance.
- A high SFA/omega-3 polyunsaturated fatty acid ((*n-3)* PUFA) ratio was correlated with lower grey matter volume (GMV) in areas of the left prefrontal cortex.
- A diet rich in PUFAs seems to exert favourable effects on the brain.

Limitations:

- This was an observational and not an intervention study.

Introduction

Ageing is a physiological process that involves both physical and mental changes. Changes include the loss of various organ functions, such as in the cardiovascular system as well as in the central nervous system, which is often expressed in impaired cognitive functions. The influence of dietary habits on cognitive performance has been investigated in numerous clinical studies with heterogeneous outcomes.

An important dietary factor influencing brain health seems to be the dietary fat composition (Dyall, 2015). Fatty acids as an essential part of human nutrition fulfil various tasks in the human organism. They serve as important energy suppliers and stores, but also as a structural component of cell membranes. Furthermore, they are the basic building blocks of many hormones and mediators as well as some signalling molecules. They are also indispensable as thermal and electrical insulators and for the mechanical protection of important organs. Long-chain omega-3 polyunsaturated fatty acids ((*n-3*) LC-PUFAs) gained increasing interest in the nutritional sciences, as they are attributed to a number of health-promoting and preventive properties

(Dyall, 2015). The two most important examples are eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). They can either be taken directly with the food or synthesised from the essential α-linolenic acid (ALA), another (*n-3*) PUFA. The endogenous synthesis of EPA and DHA is low, suggesting that the brain maintains omega-3 LC-PUFA levels mainly via the uptake from dietary sources (DeMar *et al.*, 2005, 2006). The main dietary source of EPA and DHA is cold-water fish, for example, mackerel, herring, salmon and tuna.

Epidemiological and clinical studies showed that increased intake of (*n-3*) PUFAs can both reduce the risk for and delay the symptoms of Alzheimer's dementia. A trial by Freund-Levi *et al.* (2006), suggested that in patients at a very early stage of Alzheimer's disease (AD), the decrease in cognitive performance could be delayed by supplementation of (*n-3*) LC-PUFA. In the Framingham Heart Study (Schaefer *et al.*, 2006), there was a 47% risk reduction for the development of dementia in patients with high DHA uptake and high DHA plasma levels. Furthermore, in a study by Kalmijn *et al.* (1997), increased fish consumption, an important source of (*n-3*) LC-PUFA, was associated with a reduced risk of dementia.

A possible mechanism underlying the ameliorating effects of (*n-3*) LC-PUFAs on dementia risk has been shown by Eckert *et al.* (2011). In cell cultures, they could show that DHA promoted the non-amyloidogenic processing pathway of the amyloid precursor protein (APP). This resulted in increased levels of pathophysiologically safe sAPP-α. The APP and its metabolism are of crucial importance for the development of AD.

Not only AD appears to be related to DHA. Conquer *et al.* (2000) found a lowering of DHA levels, total (*n-3*) PUFA and a lower ratio of (*n-3*) PUFA to omega-6 fatty acids/PUFA in plasma of people suffering from forms of cognitive impairment other than AD.

Dietary habits in midlife seem to exert effects on the brain over a long period of time. Eskelinen *et al.* (2008) showed that the intake of PUFAs in midlife was associated with better semantic memory later in life. Furthermore, regular fish consumption in midlife was associated with better global cognitive performance, semantic memory performance, psychomotor speed and executive functioning later in life. High intake of saturated fat was associated with poorer memory performance and an increased risk for mild cognitive impairment (MCI) in later life.

The beneficial effects of (*n-3*) LC-PUFAs on the brain do not seem to be restricted to humans. Ikemoto *et al.* (1997) showed that diets rich in (*n-3*) LC-PUFA resulted in an improved learning performance in rats. Further support for the beneficial effects of (*n-3*) LC-PUFAs on rodents' brains was shown by Hashimoto *et al.* (2002). They found an improved avoidance learning ability in AD model rats that were fed with DHA. The positive effects of DHA on learning performance in rats seem to be the result of morphological changes that are linked to dietary (*n-3*) LC-PUFA intake. Yoshida *et al.* (1997) showed that rats that were fed with omega-3 deficient had a significantly reduced vesicle density in the hippocampus after a learning task.

Taken together, there is convincing evidence that dietary (*n-3*) LC-PUFAs may improve impaired memory function and delay cognitive decline. There seem to be numerous beneficial effects of (*n-3*) LC-PUFAs on the brain that have been shown in different species. Until now, little is known about the effects of (*n-3*) LC-PUFAs on human brain morphology.

While being less well researched compared with (*n-3*) LC-PUFAs, dietary saturated fatty acids (SFA) have been negatively associated with verbal memory and other cognitive functions in a small sample of younger females (Gibson *et al.*, 2013). Moreover, several observational studies suggest that higher SFA intake may increase the risk of cognitive decline and dementia later in life (for review: (Barnard *et al.*, 2014)). The ratio of SFA intake compared to unsaturated fatty acid intake has been used in numerous studies to investigate the effects of diet on a number of different health-related outcomes (e.g. cardiovascular health, activation of carcinogens).

The purpose of this study was to investigate the association between dietary fat intake (as the ratio of SFA intake and omega-3 PUFA [SFA/(*n*-3) PUFA-ratio]) on both, cognitive performance and brain morphology in cognitively healthy adults. We hypothesised that a lower SFA/(*n*-3) PUFA ratio would be associated with better cognitive performance and increased regional grey matter density in brain areas supporting learning and memory.

Materials and methods

Participants

Participants of the current study are a subsample of the project B4 of the Neuronal Coordination – Research Network Frankfurt (NeFF) entitled 'Funktionelle und strukturelle neuronale Diskonnektion als Grundlage früher episodischer Gedächtnisstörungen der Alzheimer-Krankheit' ('Functional and structural neuronal disconnection as a basis/prerequisite for early neuronal memory dysfunction in Alzheimer's Disease'). The project was performed at the Laboratory of Neuroimaging of the Department of Psychiatry, Psychosomatic Medicine and Psychotherapy at the Goethe-University, Frankfurt am Main, Germany. Of the 267 participants that were recruited for the project B4, 118 filled in the EPIC – Food-Frequency Questionnaire (FFQ) (Bohlscheid-Thomas *et al.*, 1997) that was provided by the German Institute of Human Nutrition (DIfE). Participants that performed 1.5 standard deviations below the norm in any of the cognitive scales were excluded from the study. Finally, we included 101 cognitively healthy participants without any history of neurological or psychiatric disease according to DSM-V criteria, head injury or substance abuse (including alcohol). The ethics committee of the Medical Faculty of the Goethe-University Frankfurt approved the study and all subjects signed a written informed consent. All subjects were right-handed as assessed with the Edinburgh Handedness Inventory (Oldfield, 1971). The study was undertaken in accordance with the Code of Ethics of the World Medical Association [Declaration of Helsinki, (Rickham, 1964)].

All participants underwent apolipoprotein E (ApoE) genotyping. DNA was extracted from whole-blood samples. The DNA extraction and genotyping process were conducted at bio.logis laboratories (Frankfurt am Main., Germany). ApoE genotyping of the two single-nucleotide variants rs7412 and rs429358 was amplified using PCR and analysed with pyrosequencing. The resulting sequences were compared to established sequence variants of the ApoE allele. Twenty-nine subjects who were heterozygote for ApoE ϵ4 (ϵ3/ ϵ4), 57 subjects who were homozygote for ApoE ϵ3 and 14 subjects with the ApoE ϵ3/ ϵ2 genotype were included in the analysis.

EPIC – food-frequency questionnaire

The German version of the EPIC –FFQ was developed for the European Prospective Investigation into Cancer and Nutrition Study at the Potsdam, Germany, study centre (EPIC-Potsdam

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Study). The FFQ is a self-administered, scanner-readable questionnaire that consists of 146 items including questions about specific food items such as the frequency of sauce consumption and seasonal consumption of fruit and vegetables. Portion sizes of certain food items were estimated on the basis of coloured photographs of portion sizes or standard portion sizes such as a cup (150 ml) or jars. Additionally to the portion sizes, the frequency of consumption (1–6 times daily) was captured by the FFQ. Participants were mainly asked about their nutrition habits during the past year. The SFA/(*n-3*) PUFA ratio was calculated from the ratio of the alimentary SFA and the alimentary (*n-3*) PUFAs. Unsaturated fatty acids that were included in the ratio comprised ALA, eicosatrienoic acid (ETE), EPA, docosapetaenoic acid (DPA) and DHA. The higher the consumption of SFA and the lower the intake of omega-3 PUFAs, the higher was the value of SFA/*(n-3)* PUFA ratio.

Neuropsychological testing

Verbal learning and memory were assessed with the German version of the California Verbal Learning Test (CVLT) (Delis *et al.*, 1987, German version by Niemann *et al.*, 2008). Visual memory was tested with the Brief Visual Memory Test – R (Benedict, 1997). Additionally, measures of working memory and attention were obtained using the Letter-Number Span (Gold *et al.*, 1997), the Spatial Span of the Wechsler Memory Scale 3 (Wechsler, 1997) and Trail Making Test A (Spreen & Strauss, 1998). The verbal IQ was tested with a German verbal intelligence test (Mehrfachwahl-Wortschatz Test – B, MWTB) (Lehrl, 2005).

Depressive symptoms were assessed using the German version of the Beck Depression Inventory-2 – BDI II (Beck *et al.*, 1996, German adaptation by Hautzinger *et al.*, 2006).

Statistical analysis

Statistical analysis was done with IBM SPSS Statistics 22 (SPSS, IBM Corp., Armonk, NY, USA). To investigate the relationship between fat intake (SFA/(*n-3*) PUFA ratio) and cognitive performance, two-step hierarchical regression analyses were performed with different cognitive test scores as dependent variables. Age, sex, education, alcohol intake, body mass index and ApoE status were entered at stage one of the regression to control for these influencing variables. The SFA/(*n-3*) PUFA ratio was entered at stage two to determine the true correlation between fat intake and cognitive performance controlling for the effect of potential influencing factors.

MRI hardware and procedure

All MR images were acquired using a Trio 3T scanner (Siemens, Erlangen, Germany) with a standard head coil for radiofrequency transmission and signal reception. Participants were outfitted with protective earplugs to reduce scanner noise. For T1-weighted structural brain imaging, an optimised 3D-modified-driven equilibrium Fourier transform (3D MDEFT) sequence (Deichmann *et al.*, 2004) with the following parameters was conducted: acquisition matrix = 256 × 256, repetition time (TR) = 7.92 ms, echo time (TE) = 2.48 ms, field of view (FOV) = 256 mm, 176 slices, 1.0 mm slice thickness. A T2-weighted fluid attenuation inversion recovery (FLAIR) sequence was also acquired to ensure that vascular pathology was not significant.

Voxel-based morphometry

The voxel-based morphometry (VBM) analysis was performed using the Statistical Parametric Mapping (SPM12) software SPM12 (Wellcome Department of Cognitive Neurology, London, UK) running under MATLAB 12 (Mathworks, Sherborn, MA, USA). The structural T1 MR images were segmented into grey matter, white matter and cerebrospinal fluid using the standard unified segmentation model (Ashburner & Friston, 2005) in SPM12. Spatial normalisation was performed using the diffeomorphic nonlinear registration technique (diffeomorphic anatomical registration using exponentiated lie algebra [DARTEL]) to improve intersubject registration (Ashburner, 2007). This was followed by modulation of grey matter volume (GMV) and white matter volume (WMV) through multiplication with nonlinear components derived from the normalisation matrix to preserve tissue volume after warping. Finally, to compensate for the residual anatomical differences, the GMV and WMV images were smoothed with an FWHM kernel of 10 mm^3. After spatial pre-processing, the smoothed, modulated and normalised GMV and WMV maps were used for the statistical analysis.

Assessment of the association between the SFA/(*n-3*) PUFA ratio and grey matter as well as white matter volumes were investigated using a general linear model in SPM12 with the SFA/(*n-3*) PUFA ratio defined as covariate. To account for the effects of other influencing variables, age, gender, education, ApoE status, alcohol intake and the body mass index were included as confounding variables in the model. Since the SFA/(*n-3*) PUFA ratio and total intracranial volume (TIV) were not orthogonal, we used global scaling with TIV. To avoid possible edge effects between different tissue types, the absolute threshold masking was used to exclude voxels with GM or WM values of less than 0.2. Threshold-Free Cluster Enhancement (TFCE, running in the cat12 toolbox, http://www.neuro.uni-jena.de/cat/) was used to correct for multiple comparisons (Smith & Nichols, 2009). This method estimates a voxel value that represents the accumulative cluster-like local spatial support at a range of cluster-forming thresholds. TFCE does not need an arbitrary cluster-forming threshold and combines statistics based on the local significance as well as the spatial extent of this effect (Kurth *et al.*, 2015).

Results

Population characteristics

The study population included 101 individuals (age: 42.3 ± 21.3 years, 62 females). Table 1 depicts the population characteristics.

Hierarchical regression analysis between dietary fat intake and cognition

The hierarchical multiple regression revealed that at stage one, alcohol intake, gender, age, education, BMI and ApoE status did not contribute significantly to the regression model, ($F(6.92) = 1{,}561$, $p = 0.17$) and accounted for 9.2% of the variation in repetition errors. Introducing the SFA/(*n-3*) PUFA ratio explained an additional 4.4% of the variation in repetition error and this change in R^2 was significant at an alpha level of 0.05, $F(7.91) = 2.05$, $p = 0.034$. Together, the five independent variables accounted for 13.6 % of the variance in repetition error (see Table 2). The repetition error is the sum of all items that were erroneously repeated during recall across all trials of the CVLT. Repetition errors can have the form of perseverations (the same word is repeated

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Table 1. Demographics and nutrition indices

Gender male/female (n)	39/62
Age (mean/SD)	42.29 (± 21.31)
Years of education (mean /SD)	16.70 (± 3.39)
BMI (mean/SD)	25.15 (±6.34)
ApoE ϵ4/ApoE ϵ2/ApoE ϵ3/ϵ3 (n)	28/16/57
MWTB (mean/SD)	118.06 (± 13.58)
BDI-II (mean/SD)	4.13 (± 4.66)
Alcohol intake (g/d) (mean/SD)	13.59 (± 14.28)
Caloric intake (kj/d) (mean/SD)	9657.85 (± 3166.26)
(*n-3*)PUFA intake (g/d) (mean/SD)	2.90 (±1.36)
SFA-intake (g/d) (mean/SD)	41.68 (±16.04)
SFA/(*n-3*)PUFA ratio (mean/SD)	15.46 (±4.87)

BMI, body mass index; MWTB, Mehrfachwahl Wortschatz Intelligenz Test - B; BDI-II, Beck Depression Inventory-2.

Table 2. Summary of hierarchical regression analysis for variables predicting repetition error

Variable	B	SE B	β	
Step 1				
Age	0.02	0.02	0.15	
Gender	−0.76	0.71	−0.12	
Education	−0.21	0.09	−0.24	$p = 0.023$
Alcohol (g/day)	0.01	0.03	0.07	
BMI	−0.01	0.05	−0.02	
ApoE	−0.15	0.43	−0.04	
Step 2				
Age	0.04	0.02	0.27	$p = 0.030$
Gender	−0.94	0.70	−0.15	
Education	−0.21	0.09	−0.23	$p = 0.023$
Alcohol (g/day)	0.01	0.03	0.06	
BMI	−0.01	0.05	−0.02	
ApoE	−0.05	0.43	−0.01	
SFA/(*n−3*) PUFA ratio	0.15	0.07	0.25	$p = 0.034$

$R^2 = 0.092$ for Step 1, $\Delta R = 0.044$ ($p < 0.05$),
B, unstandardised Beta; ß, standardised Beta; SE B, standard error of B.

immediately after it has been recalled) or they can have the form of distal repetition errors (repeated words are separated by other recalled words from the list). Repetition errors reflect a dysfunction of source memory.

For all other cognitive variables (e.g. Letter-Number Span, Brief Visual Memory Test, Trail Making Test A, Spatial Span), dietary fat composition was not a significant ($p < 0.05$) predictor for cognitive performance.

Correlation between dietary fat intake and brain morphology

VBM revealed a significant association between SFA/(*n-3*) PUFA ratio and cortical GMV in two areas (Brodmann area 6 and Brodmann area 10) of the left prefrontal cortex ($p < 0.001$, TFCE corrected.), while controlling for the influence of age, gender, sex, education, BMI, ApoE, education and alcohol intake (see Fig. 1). A higher SFA/(*n-3*) PUFA ratio was associated with decreased grey matter density in these areas (Table 3). For visualisation purposes, log scaled p-maps with colour bars indicating significant voxels ($p < 0.001$, corrected using TFCE) were superimposed on an averaged (152) MNI template.

Table 3. Brain coordinates of GM volume associated with SFA/(*n-3*) PUFA ratio

		MNI coordinates		
Brain area	No. of voxels	x	y	z
Supplementary motor and premotor area (BA6), left	78	−21	27	58
Dorsolateral prefrontal cortex (BA10), left	78	−24	60	22

Discussion

Consistent with other studies that have shown beneficial effects of a diet high in LC-PUFAs on the brain, we could show that a low SFA/(*n-3*) PUFA ratio was associated with better cognitive performance and higher grey matter density in the superior frontal cortex.

Several randomised controlled studies with (*n-3*) PUFA supplementation have shown improved cognitive performance in the intervention group. The beneficial effects of (*n-3*) PUFAs on brain function included improved executive functions (Johnson *et al.*, 2008; Witte *et al.*, 2014) and improved memory performance (Nilsson *et al.*, 2012; Kulzow *et al.*, 2016). In a randomised double-blind intervention study by Witte *et al.* (2014), cognitively healthy participants aged between 50 and 75 years either received high daily doses of (*n-3*) PUFAs in the form of fish oil (2.2 g/day) or placebo over a period of 26 weeks. Using a neuropsychological test battery, Witte *et al.* (2014) could show an enhancement of executive functions in participants that were supplemented with (*n-3*) PUFAs compared to the placebo group. Moreover, a dose of 2.2 g/day of marine (*n-3*) PUFAs resulted in an improvement of object location memory. Interestingly, enhancement of memory performance following (*n-3*) PUFA supplementation was restricted to a specific form of memory (object location memory), while other memory domains (e.g. verbal memory) did not profit from the PUFA supplementation. Similarly, we just found an association between one specific memory domain (repetition error) and SFA/(*n-3*) PUFA ratio.

One possible mechanism underlying the beneficial effects of (*n-3*) LC-PUFAs on cognition is an enhancement of cerebral perfusion. Konagai *et al.* (2013) showed that a supplementation with krill oil (193 mg/day EPA and 92 mg/day DHA) or sardine oil (491 mg/day EPA and 251 mg/day DHA) for a duration of 3 months resulted in significantly greater changes in oxyhemoglobin concentration during a working memory task compared to the placebo group in healthy older adults (aged 60–70). Interestingly, a supplementation with (*n-3*) PUFA seems to increase cerebral perfusion primarily in frontal areas of the brain (Jackson *et al.*, 2012; Konagai *et al.*, 2013). This finding is in line with our finding of an association between SFA/(*n-3*) PUFA ratio and grey matter density in two areas that are located in the frontal cortex.

In addition to enhanced cerebral perfusion, beneficial effects of (*n-3*) PUFA on the brain also comprise an enhancement of brain plasticity. DHA has been shown to have beneficial effects on

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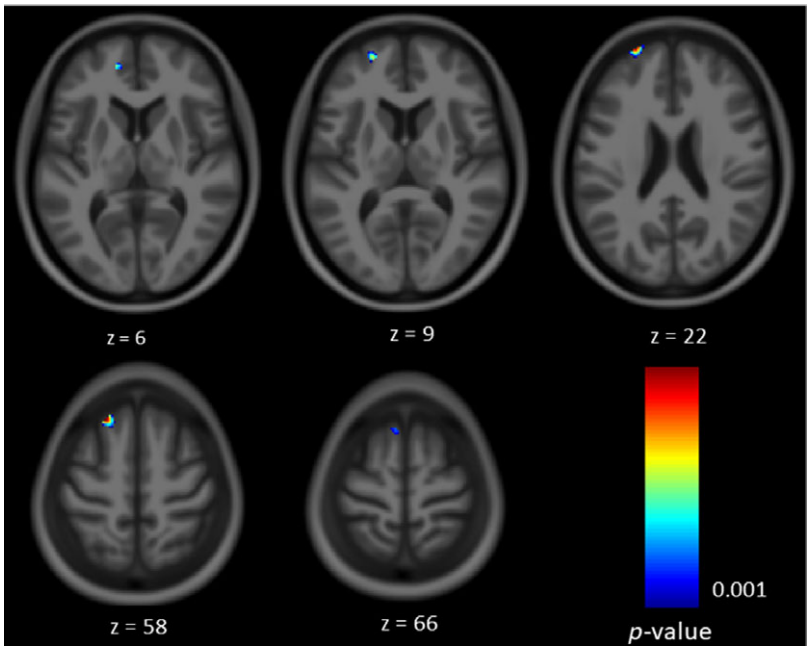

Fig. 1. Association between SFA/(*n3*) PUFA ratio and cortical GMV in two areas (Brodmann area 6 and Brodmann area 10) of the left prefrontal cortex ($p < 0.001$, TFCE corrected.). A higher SFA/(*n3*) PUFA ratio was associated with decreased grey matter density in these areas. Log scaled p-map with colour bar indicating significant voxels ($p < 0.001$, corrected using TFCE), superimposed on an MNI template. Images are displayed in a neurological convention, and coordinates according to MNI.

neurite outgrowth in terms of overall length and complexity of outgrowth in rat brain (Ikemoto *et al.*, 1997; Calderon & Kim, 2004; Cao *et al.*, 2009). Moreover, DHA promotes synaptogenesis and synaptic expression of synapsin, and glutamate receptors in rat hippocampal neurons (Cao *et al.*, 2009) Both, DHA and EPA have been shown to enhance differentiation of neural stem cells, thereby promoting neurogenesis (Katakura *et al.*, 2009). In addition to enhancing cerebral perfusion and promoting neurogenesis, DHA and EPA also have been shown to have anti-inflammatory effects on the brain (Dyall, 2015). These anti-inflammatory effects are a result of (*n-3*) LC-PUFA-mediated alterations in cytokine levels and seem to have a positive effect on age-related impairments in long-term potentiation (Martin *et al.*, 2002). Taken together, (*n-3*) PUFA act on the brain, preventing inflammation, enhancing cerebral perfusion and neuroplasticity and thereby improving cognition.

Studies showing the beneficial effects of (*n-3*) PUFA on brain plasticity have been mostly done in rodents. However, there are also a few studies that have investigated the association between dietary intake and brain morphology in humans (Titova *et al.*, 2013; Witte *et al.*, 2014; Gu *et al.*, 2015). In line with our findings, all studies found a positive effect of (*n*-3) PUFA consumption on GMV. Gu *et al.* (2015) found a positive association between fish consumption and total GMV, as well as GMV in the cingulate cortex, parietal lobe, temporal lobe and hippocampus. Similar to our study, the study by Gu *et al.* was an observational study with no (*n-3*) supplementation. In an interventional study with high doses of (*n-3*) PUFAs (2.2 g/day), Witte *et al.* (2014) found an increase in GMV in core regions for episodic memory. Using diffusion tensor imaging (DTI), they could also show (*n-3*) PUFA-induced microstructural changes in fibre tracts within the anterior corpus callosum, which connects prefrontal areas. These changes have been interpreted by the authors of the study as improvement of microstructural integrity. An association between (*n-3*) PUFA intake and structural changes in areas of the prefrontal cortex (Brodmann area 6) was also found in our study, albeit at the level of GMV.

The prefrontal cortex has been investigated extensively for its involvement in memory processes. Left supplementary motor and premotor areas (BA6) have been implicated in the storage and manipulation of verbal information. The frontopolar prefrontal cortex (BA10) seems to play a role in memory recall (Smith & Jonides, 1999; Miller & Cohen, 2001). Our finding of an association between the SFA/(*n-3*) PUFA ratio and grey matter density in these areas implies that high intake of (*n-3*) fatty acids might affect plasticity in brain areas that are important for working memory. This assumption is supported by our finding of better memory performance in participants that had a low SFA/(*n-3*) PUFA ratio.

Our study has some important limitations. First, this was a cross-sectional observational study and not an intervention study. An observational dietary study does not allow to calculate precise amounts of (*n-3*) PUFA intake, since it relies on the nutrition records of the participants. Thus, there might have been some over- or underestimation of PUFA intake by the participants. Direct assessment of fatty acid composition in erythrocytes, for example, would have improved the accuracy of current dietary fatty acids.

A further limitation of our study is the number of subjects. With a larger sample size and thus more statistical power, we might have been able to find effects of SFA/(*n-3*) PUFA intake not only on one measure of memory (repetition error), but also on other memory measures.

Lastly, as this is just a correlational study, our results do not prove a causal relationship between dietary fatty acid composition and cognition/morphometry. However, they contribute to the growing body of evidence as they are in line with existing research and, as such, support a beneficial role of a diet high in (*n-3*) PUFA and low in SFA for brain health.

Conclusion

Our findings of better memory performance in participants that had a diet rich in PUFAs together with morphological alterations in frontal areas that play an important role in a number of memory

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processes underline the role of dietary fat composition on both cognition and brain health. A diet high in (*n-3*) PUFAs seems to exert favourable effects on both, cognitive performance and synaptic density, thereby constituting a possible prevention strategy for maintaining cognitive health in older age.

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Conflict of interest. The authors have no conflicts of interest to declare.

Authors contributions. SM, FF, DP, NM, VO and TK collected the data. JP, AR, SM and DP designed the study. SM, DP and NM processed the data and analysed. SM and TK wrote the manuscript. All authors edited the manuscript.

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