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Title: Prospective associations between dietary patterns and cognitive performance during adolescence

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Abstract

Purpose: The aim of the study was to investigate prospective associations between dietary patterns and cognitive performance during adolescence.

Methods: Participants were sourced from the Western Australian Pregnancy Cohort (Raine) Study that includes 2868 children born between 1989 and 1992 in Perth, Western Australia. When the children were 17 years old (2006- 2009), cognitive performance was assessed using a computerized cognitive battery of tests (CogState) that included six tasks. Using a food frequency questionnaire administered when the children were 14 years old (2003- 2006), 'Healthy' and 'Western' dietary patterns were identified by factor analysis. Associations between dietary patterns at 14 years of age and cognitive performance at 17 years of age were assessed prospectively using multivariate regression models.

Results: Dietary and cognitive performance data were available for 602 participants. Following adjustment for the "Healthy" dietary pattern, total energy intake, maternal education, family income, fathers presence in the family, family functioning and gender, we found that a longer reaction time in the detection task (β= 0.016; 95% CI: 0.004; 0.028; p= 0.009) and a higher number of total errors in the Groton Maze Learning Test- delayed recall task (β= 0.060; 95% CI: 0.006; 0.114; p= 0.029) were significantly associated with higher scores on the 'Western' dietary pattern. The "Western" dietary pattern was characterised by high intakes of take away food, red and processed meat, soft drink, fried and refined food. We also found that within the dietary patterns, high intake of fried potato, crisps and red meat had negative associations, while increased fruit and leafy green vegetable intake had positive associations with some aspects of cognitive performance.

Conclusion: Higher dietary intake of the "Western" dietary pattern at age 14 is associated with diminished cognitive performance three years later, at 17 years.

Keywords: nutrition; dietary pattern; cognition; adolescents; Raine study

Abbreviations:

CPAL: Continuous Paired Association Learning Task

DET: Detection Task

IDN: Identification Task

FFQ: Food Frequency Questionnaire

GML: Groton Maze Learning Test

GMR: Groton Maze Learning Test- delayed recall

OCL: One Card Learning Task

Introduction

Adolescence represents a critical time period for brain development (Steinberg, 2005). During adolescence, structural and functional reorganisation of the brain takes place, which is partly the result of endocrinological changes during puberty (Blakemore et al., 2010). The brain development of adolescents is characterized by significant reorganization within the prefrontal cortex, including synaptic pruning, myelination and a growing number of connections between different brain regions (Lenroot and Giedd, 2006, Steinberg, 2005).

Nutrition is one of the key environmental factors that influences genetically programmed development in the human brain (Nyaradi et al., 2013). Numerous studies have investigated how nutrition during early childhood influences cognitive brain development. However, limited literature is currently available concerning the association between nutrition and cognitive performance during adolescence. High fish consumption (Åberg et al., 2009), regular intake of breakfast (Widenhorn-Müller et al., 2008), a high nutrient/low glycaemic index mixed grain diet (Chung et al., 2012), and iron (Bruner et al., 1996) and zinc (Tupe and Chiplonkar, 2009) supplementation have all been associated with improved cognitive performance in cross-sectional studies of adolescents. However, there is a paucity of research investigating diet as a whole and its relationship with cognitive development during adolescence (Nyaradi et al., 2013).

Investigating diet as a whole is important for two main reasons. First, evaluating single nutrients may not reflect the whole diet consumed by individuals (Jacques and Tucker, 2001). Second, diet as a whole (rather than single nutrients) represents a more modifiable factor which is important for public health interventions (Nishida et al., 2004).

In this study, we investigated the whole diet (in the form of dietary patterns), consumed by adolescents, and their prospective associations with cognitive performance. We hypothesized that dietary patterns at 14 years of age (by which time a majority of adolescents have commenced pubertal changes (Christie and Viner, 2005)) would exert a significant influence on cognitive performance at 17 years.

Methods

Study population

The adolescents taking part in this study were recruited from the Western Australian Pregnancy Cohort (Raine) Study. Details of the original study are reported elsewhere (Newnham et al., 1993). In brief, 2,900 women were recruited in Perth, Western Australia into a randomised controlled trial to evaluate the effects of pregnancy ultrasounds. Women between 16 to 20 weeks' gestation were randomly selected from King Edward Memorial Hospital and surrounding private practices in Perth, Western Australia between 1989 and 1991. The families of the cohort (which initially included a total of 2,868 babies, born between 1989 and 1992) were followed up at regular intervals at Princess Margaret Hospital for Children (Perth, Western Australia)**.** Ethics approval for the Raine Study was granted by The Human Ethics Committee at both hospitals. Consent has been provided by the parents at each follow- up and when the children turned 18, they provided consent for themselves to continue to use their information. In the current study, we analysed data from the 14 year and the 17 year follow-ups to assess the association between dietary patterns and cognitive performance.

Dietary pattern

Dietary patterns were identified using food intake data collected with an evaluated semi-quantitative food frequency questionnaire [(FFQ) Commonwealth Scientific and Industrial Research Organisation (CSIRO), Adelaide, Australia (Baghurst and Record, 1983 , Baghurst and Record, 1984)], administered to participants at 14 years of age. The primary caregiver completed the FFQ in consultation with the study participant. We assessed adolescents' dietary intake over the previous 12 months using the FFQ. Details of the methodology and the reliability of the FFQ have been published elsewhere (Ambrosini et al., 2009a, Ambrosini et al., 2009b). In short, average daily intakes of 212 foods were estimated by the FFQ and grouped into 38 major food groups, all of which were included in a factor analysis to derive dietary patterns. The analysis was limited to factors with an eigenvalue >1 and varimax rotation was used to improve the separation of the factors. Two major dietary patterns were identified and labelled as "Healthy" (high in fruits, vegetables, whole grains, legumes and fish) and "Western" (high intake of take-away foods, red and processed meat, soft drink, fried and refined food) (Ambrosini et al., 2009b). Participants received a z-score for each dietary pattern, indicating how closely their reported intake reflected these dietary patterns. We also examined the component food groups of both dietary patterns that received the highest factor loadings. Total energy intake was estimated by linking estimated food intakes from the FFQ with Australian Food Composition Tables (Ambrosini et al., 2009b). The dietary patterns and their factor loadings are presented in Appendix 1.

Cognitive performance

Cognitive performance was measured using the CogState (CogState Ltd, Melbourne, Australia) computerized cognitive battery, administered to 717 Raine Study participants at 17 years (between 2006 and 2009). The CogState test is appropriate to use in different cultures, with only minimal language requirements to undertake the battery (CogState, 2001). The computerized test format is particularly well suited to children and adolescents, as it uses card games to measure cognitive performance. The CogState software assesses core neurocognitive domains in a reliable and sensitive manner; it has been validated and found to be reliable in a range of participant age groups (including adolescents) and clinical populations (Collie et al., 2003, Mollica et al., 2005, Dingwall et al., 2009, Maruff et al., 2009, Falleti et al., 2006, Lim et al., 2013). It has correlated well (r's= 0.49 to 0.83) with similar conventional neuropsychological measures (Maruff et al., 2009), and has been shown to manifest limited practice effects (Falleti et al., 2006).

We used the main outcome measures derived from seven CogState tasks in the present study, including the Detection Task (DET- main outcome measure: reaction time, with a lower score representing better performance), Identification Task (IDN – main outcome measure: reaction time, with a lower score again representing better performance), One Card Learning Task (OCL - main outcome measure: proportion of correct responses, with a higher score representing better performance), Continuous Paired Association Learning Task (CPAL - main outcome measure: total number of errors, with a lower score representing better performance), Groton Maze Learning Test (GML – main outcome measure: total number of errors, with a lower score representing better performance) and Groton Maze Learning Test- delayed recall (GMR - main outcome measure: total number of errors, with a lower score representing better performance). The main cognitive domains measured are as follows: psychomotor functioning (DET), visual attention (IDN), memory and attention (OCL), visual learning and memory (CPAL) and memory and executive function (GML and GMR). Details of the CogState test are presented in Appendix 2.

Measurement of confounders

We considered sociodemographic and family characteristics as potential confounders in the analyses. These included maternal education, family income, the presence of the biological father in the family and family functioning. Maternal education was categorized into eight categories: i) did not finish high school; ii) finished high school and completed the tertiary entrance exam; iii) trade/apprentice certificate; iv) college/TAFE (Technical and Further Education) certificate; v) diploma; vi) bachelor degree; vii) postgraduate degree; and viii) ‘other’. In the Raine study, maternal education data were collected only in pregnancy and at the eight year follow up. For this study, we used maternal education measured when the child was eight years old, as this represented data from the closest timepoint to adolescence available within the Raine cohort. Family income at the 14 year follow up was specified across four categories: ≤ $25,000; $25,001 - $50,000; $50,001 - $78,000; and >$78,000 per annum. The presence of the biological father in the family was dichotomised as ‘yes’ or ‘no’. Family functioning was assessed by the McMaster Family Assessment Device (Epstein et al., 1983); this included questions about family communication, problem solving, affective responsiveness and behaviour control, with higher scores indicating better family functioning. Family characteristics data were obtained at the 14 year follow up between 2003 and 2005.

Statistical analysis

As specified in the CogState guidelines, those adolescents who did not pass CogState data integrity checks and did not complete 75% of the trials of the Detection (DET), Identification (IDN), and One Card Learning (OCL) tasks were omitted from the statistical analysis. The integrity check criteria include: DET speed scores < IDN; speed scores and DET accuracy > 90%; IDN accuracy > 80%; OCL accuracy > 50%. The square root of the proportion of correct responses on the OCL task was arcsine transformed and the reaction time scores of DET and IDN were $\log_{10}$ transformed, as per standard CogState protocols. Since these data were positively skewed, a $\log_{10}$ transformation of the total error data was undertaken for the following variables: Continuous Paired Association Learning Task (CPAL), Groton Maze Learning Test (GML) and Groton Maze Learning Test - delayed recall (GMR).

The data were inspected via summary statistics, and then analysed in two steps using linear regression models. Model one was minimally adjusted for diet related variables and included z-scores for the ‘Western’ and ‘Healthy’ dietary patterns and total energy intake only. In our analysis we wanted to specifically focus on the influence of dietary patterns (i.e., the types of foods that are consumed in combination) on cognitive performance, independent of total energy consumption. In model two we additionally adjusted for maternal education, family income, the presence of biological father in the family, family functioning and gender. In addition, we examined key food groups (with a factor loading ≥0.030) in the “Healthy” and “Western” dietary patterns (Appendix 1) to identify components of the dietary patterns that may explain associations with each cognitive task, analysed using multiple regression models adjusting for all covariates. The intakes of key food groups were converted into binary variables (median intakes for cut-offs), representing low and high consumption of each. All analyses were performed using IBM SPSS Statistics 19. Results were reported using a significance level of 0.05.

Results

Complete data for dietary patterns at age 14 were available for 1611 adolescents and for cognitive performance at age 17 for 717 adolescents. When combining data for dietary patterns and cognitive performance, data were available for 602 adolescents (288 females and 314 males). Family income was greater than AUS$78,000 in 39% of participants, and the biological father was present in 70% of families at age 14 (Table 1). The adolescents who participated in the CogState cognitive battery at the 17 year follow up in the Raine Study were born to mothers who were more likely to have received more education, to live with the child's biological father and to have higher incomes, compared with adolescents from the Raine cohort who did not participate in CogState testing at age 17.

[Table 1 position]

Table 2 presents the results of the linear regression models for each cognitive task compared with dietary patterns. In the minimally adjusted model (model one), one standard deviation unit- higher z-score for the "Western" dietary pattern at 14 years of age was associated with longer reaction times on the tasks DET (β= 0.018; 95% CI: 0.007; 0.030; p= 0.002) and IDN (β= 0.011; 95% CI: 0.000; 0.022; p= 0.042), a higher number of errors on the GMR task (β= 0.066; 95% CI: 0.014; 0.118; p= 0.012) and fewer correct responses on the OCL task (β= -0.019; 95% CI: -0.037; -0.002; p= 0.032). Further, a one standard deviation unit higher z-score on the 'Healthy' dietary pattern was significantly associated with fewer errors on the CPAL (β= -0.055; 95%CI: -0.101; -0.010; p= 0.017) and GML (β= -0.023; 95% CI: -0.045; -0.002; p= 0.035) tasks. Figure 1 shows a clear linear association between the predicted values of each cognitive task, based on model one, and the z- scores of the "Western" and "Healthy" dietary patterns in the plots. Examining the worst dietary patterns (cases with lowest healthy or cases with highest western patterns) and the best dietary patterns (highest healthy or lowest western patterns) for cases in the first and 99th percentiles of these dietary pattern z-scores gave the following results for the DET and GMR tasks. DET mean reaction time for the worst dietary patterns was 339.0 milliseconds (range 320.1 - 367.1), and for the best dietary patterns was 295.3 milliseconds (range 287.4 - 311.6). GMR mean error rate for the worst dietary patterns was 18.4 (range 13.2 -25.6) and for the best dietary patterns was 11.7 (range 9.3-15.9). Thus, having worst dietary patterns increases the average reaction time by 44 milliseconds and the mean error rate by almost seven, which represent substantial differences in cognitive testing scores.

After adjustment for confounders in model two, these results were attenuated. Only a longer reaction time in the DET task (β= 0.016; 95% CI: 0.004; 0.028; p= 0.009) and a higher number of total errors in the GMR task (β= 0.060; 95% CI: 0.006; 0.114; p= 0.029) remained significantly associated with a higher z-score for the “Western” dietary pattern at 14 years. The associations with IDN and OCL remained similar but were no longer statistically significant.

When analysing the intake of the key food groups of each of the dietary patterns in association with cognitive performance in fully adjusted models, we found that low intake (≤8.57 g/day) of green leafy vegetables was associated with longer reaction time on the DET task (β=0.014; 95% CI: 0.002; 0.026; p=0.028) and low intake (≤201.3 g/day) of fresh fruits was associated with higher number of errors on the GML task (β=0.035; 95% CI: 0.001; 0.070; p=0.044). Significant associations were observed between high intake (≥13.58 g/day) of fried potatoes (French fries) and longer reaction times on the DET (β= 0.014; 95% CI: 0.026; 0.001; p=0.035) and IDN (β=0.014; 95% CI: 0.026; 0.003; p=0.013) tasks, and with higher number of errors on the CPAL task (β=0.112; 95% CI: 0.185; 0.040; p=0.003). High intake (≥4.29 g/day) of crisps (potato chips) was significantly associated with longer reaction time on the DET (β=0.013; 95% CI: 0.026; 0.001; p=0.037) task and fewer correct responses on the OCL task (β= -0.020; 95% CI: -0.001; -0.039; p=0.037). High intake (≥60.32 g/day) of red meat was associated with significantly fewer correct responses on the OCL task (β= -0.022; 95% CI: -0.002; -0.042; p=0.029).

[Table 2 position]

[Figure 1 position]

Discussion

In this study of adolescents, we found that a higher intake of the "Western" dietary pattern was associated with poorer cognitive performance in adolescents. After adjustment of possible confounders, we found that performance on two cognitive tasks at age 17 (DET and GMR, which measures psychomotor speed and visual spatial learning and long term memory respectively) were significantly associated with the level of consumption of the 'Western' dietary pattern at age 14. There was some suggestion that this dietary pattern was also associated with visual attention and working memory as indicated by the IDN and OCL performance tests.

The findings of this study suggest an association between diet during the 'sensitive' adolescent years of brain development and cognitive performance approximately 3 years later. Previous cross-sectional analyses have found that the "Healthy" and "Western" dietary patterns are associated with specific mental health profiles in the Raine study cohort (Howard et al., 2011, Oddy et al., 2009). To our knowledge, this current study is the first that shows a prospective association between dietary patterns and cognitive performance in adolescents. The main focus of previous research in adolescents has been on micronutrient supplementation (Bruner et al., 1996, Tupe and Chiplonkar, 2009), fish consumption (Åberg et al., 2009) and breakfast intake (Widenhorn-Müller et al., 2008) in association with cognitive performance. A few studies have examined diet quality and academic achievements during adolescence (Florence et al., 2008, Øverby et al., 2013) and cognitive performance is a predictor of school performance (Clark et al., 2010). In particular, one cross-sectional study found that a higher intake of unhealthy foods including sugar-sweetened soft drinks, snacks and fast food was associated with self-reported difficulties in mathematics in adolescents (Øverby et al., 2013).

The recent advancement in medical imaging has made it possible to study the adolescent brain in greater detail than was previously possible (Giedd, 2008). As Giedd stated, adolescence is ‘a time of great risk and great opportunity’, because of the neurobiological changes which occur in the teenage brain (Giedd, 2008). It is possible that poor diet is a significant risk factor during this period of brain development; indeed our findings support this proposition.

The ”Western” dietary pattern in our study was high in the consumption of ‘take away’ foods, red and processed meat, soft drink, fried and refined food. It also strongly correlated with high intake of total fat, saturated fat, refined sugar and sodium (Ambrosini et al., 2009b). High saturated fat and simple carbohydrate intake have both been linked to impairment in the functioning of the hippocampus, which is a brain structure that is centrally involved in learning and memory (Kanoski and Davidson, 2011). The hippocampus is also one of the brain structures that increases its volume during adolescence (Giedd, 2008). Further, a “Western” style diet has been shown in rodents to decrease the level of brain-derived neurotrophic factor (BDNF), which has an important role in the growth and function of neurons and which has been shown to influence hippocampal synaptic plasticity and neurogenesis in animal models (Stranahan et al., 2008). A ”Western” diet also alters the regulation of glucose, causes neuroinflammation and damages the structure of the blood-brain barrier; these physiological changes in the brain have been shown to impair cognitive performance in both animal and human studies (Kanoski and Davidson, 2011). Similar changes may occur during adolescence, when the still developing brain is especially sensitive to neurohormonal influences associated with puberty (Blakemore et al., 2010).

We found in our study that within the dietary pattern component food groups, high intake of fried potato (French fries), crisps (potato chips) and red meat had negative associations with some elements of cognitive performance, while increased fruit and leafy green vegetable intake had positive associations. Fried potatoes (French fries), crisps (potato chips) and red meat contain a high amount of saturated fat and omega-6 fatty acid. A balanced ratio (1:1) of omega-3: omega-6 fatty acid, important for metabolic pathways, has shifted in the “Western” type diet resulting in a ratio of 1:20/25 meaning humans consume less omega-3 and more omega-6 fatty acids (Simopoulos, 2011). In a recent study, researchers reported better cognitive functioning in seven to nine year old children with lower ratios of omega-3 to omega-6 fatty acids (Sheppard and Cheatham, 2013). Conversely, the association between higher intake of fruit and leafy green vegetables and better cognitive performance may be due to increased micronutrient content. Leafy green vegetables are particularly high in folate, which has been implicated in the enhancement of cognitive development (Nyaradi et al., 2013).

Our study has a number of strengths. We were able to analyse prospective relationships between dietary patterns and cognitive function in a modest sample of adolescents. As another strength, we measured cognitive performance using a computerized cognitive battery of tests (CogState) which are valid, reliable and sensitive to identifying changes in an individual’s cognitive status (Collie et al., 2003, Mollica et al., 2005). Lastly, we adjusted for a number of plausible confounders including maternal education, family income, the presence of the biological father in the family and family functioning.

A limitation of our study was that we were not able to adjust for maternal intelligence. However, maternal education (which we adjusted for) has been shown to be a reliable proxy measure for maternal intelligence (Deary et al., 2007) and is associated with dietary patterns in offspring (Ambrosini et al., 2009b). As another relative weakness, data on cognitive performance and dietary patterns were available for 602 adolescents, which represented less than a quarter of the original Raine cohort (23%). The individuals who were evaluated in the current study were derived from families with more affluent and better educated socioeconomic backgrounds compared to the overall Raine cohort. Lastly, we acknowledge that the results of our study are attenuated by control for social advantage, and we cannot rule out the importance of other confounding factors that we were not able to control for in this study; therefore, we cannot state definitely that there is a causative association between diet and brain functioning during adolescence.

In conclusion, we identified a ‘Western’ dietary pattern as a risk factor for poorer cognitive performance during adolescence. These findings have important implications for future health policies and health promotion programs. Adolescents may be likely to consume foods of a “Western” dietary pattern due to peer and marketing influences, more independence over food choices and in purchasing of food outside the home. More studies are needed to replicate these findings in a larger study population, and extend the findings by investigating the mechanisms which underpin the link between diet and cognitive function.

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Table 1 Frequency characteristics for participants, who have at least one CogState outcome measure and dietary pattern score

	Sample (n= 602)	
Continuous variables	***Mean (Range)***	***(SD)***
Detection Task (DET- millisecond) * n= 409	274.16 (204.17- 446.68)	1.14
Identification Task (IDN- millisecond)) * n= 551	436.52 (323.59- 724.44)	1.15
One Card Task (OCL- correct response) * n= 556	0.85 (0.71- 0.99)	0.10
Continuous Paired Association Learning Task (CPAL- total error)) * Part 1 and Part 2 n= 602	30.12 (0- 212)	28.30
Groton Maze Learning Test (GML- total error)) * n= 589	81.80 (23- 463)	53.06
Groton Maze Learning Test- delayed recall (GMR- total error) * n= 600	8.58 (0- 83)	8.18
Energy intake (KJ) n= 602	9,278 (3,370- 19,769)	2,829
“Western” dietary pattern (z-score)	-0.1251 (-1.69- 2.71)	0.033
“Healthy” dietary pattern (z-score)	-0.0203 (-1.88- 2.92)	0.032
Red Meat (g/day)	62.46 (0- 279.94)	1.46
Fried potato ((French fries) (g/day)	14.32 (0- 69.66)	0.51
Crisps (potato chips) (g/day)	8.23 (0- 60)	0.38
Green leafy vegetables (g/day)	11.32 (0- 147.52)	0.44
Fruit (g/day)	233.79 (0- 1131.17)	7.71
Family functioning score n= 596	1.78 (1- 3.33)	0.44
Categorical variables	***(n)***	***%***
Gender of the child n= 602		
female	288	47.8
male	314	52.2
Maternal education n= 568		
not finished high school	114	20.1
finished high school, tertiary entry exam	84	14.8
trade/apprentice certificate	24	4.2
collage/TAFE certificate	104	18.3
diploma	76	13.4
bachelor degree	87	15.3
postgraduate degree	55	9.7
other	24	4.2
Family income n= 593		
<= AUS$25,000	62	10.5
AUS$25,001 - AUS$50,000	137	23.1

AUS$50,001 - AUS$78,000	163	27.5
>AUS$78,000 per annum	231	39
Father living with family n= 601		
yes	423	70.4
no	178	29.6

* means, ranges and standard deviations are calculated on untransformed data (those variables that were transformed by CogState were also back transformed)

Table 2 Regression models: dietary patterns at age 14 and cognitive performance (CogState test) at age 17

CogState tasks[a,b]		Model 1*		Model 2**	
		β (95% CI)	P	β (95% CI)	p
DET n= 409 (reaction time)	Healthy	-0.004 (-0.012; 0.004)	0.296	-0.003 (-0.011; 0.005)	0.439
	Western	0.018 (0.007; 0.030)	0.002	0.016 (0.004; 0.028)	0.009
IDN n= 551 (reaction time)	Healthy	-0.003 (-0.010; 0.004)	0.393	-0.003 (-0.010; 0.005)	0.440
	Western	0.011 (0.000; 0.022)	0.042	0.011 (0.000; 0.022)	0.060
OCL n= 556 (correct responses)	Healthy	-0.004 (-0.015; 0.008)	0.556	-0.003 (-0.016; 0.010)	0.635
	Western	-0.019 (-0.037; -0.002)	0.032	-0.017 (-0.036; 0.002)	0.081
CPAL n= 602 (total error)	Healthy	-0.055 (-0.101; -0.010)	0.017	-0.023 (-0.071; 0.026)	0.365
	Western	0.024 (-0.043; 0.092)	0.482	0.026 (-0.045; 0.097)	0.469
GML n= 589 (total error)	Healthy	-0.023 (-0.045; -0.002)	0.035	-0.015 (-0.038; 0.008)	0.205
	Western	0.010 (-0.022; 0.043)	0.529	0.004 (-0.030; 0.038)	0.808
GMR n= 600 (total error)	Healthy	-0.001 (-0.036; 0.034)	0.953	0.003 (-0.035; 0.040)	0.888
	Western	0.066 (0.014; 0.118)	0.012	0.060 (0.006; 0.114)	0.029

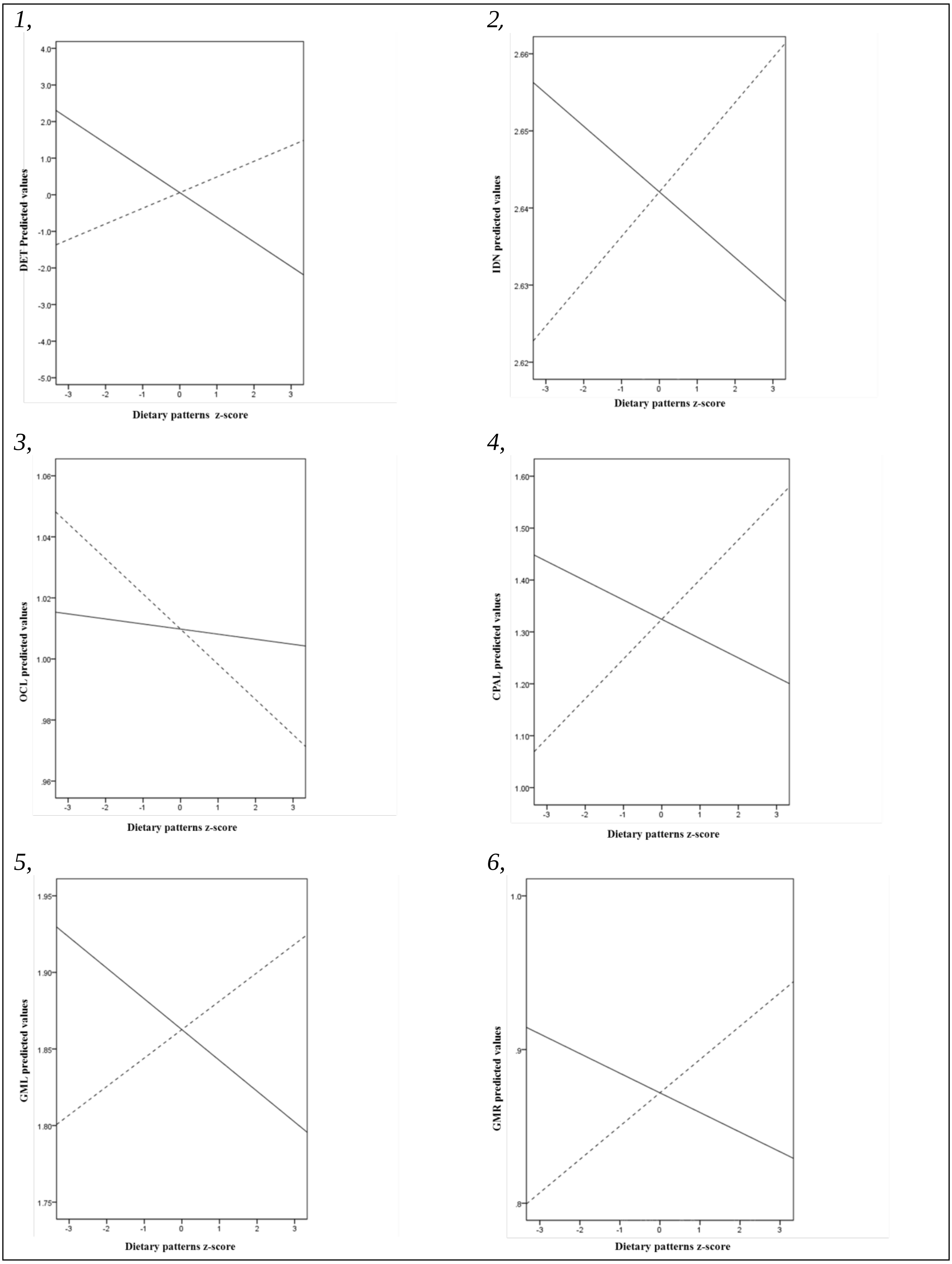
*Model 1 includes: Healthy and Western dietary pattern, total energy intake.

**Model 2 includes: all in model 1 and maternal education, family income, the presence of biological father in the family, family functioning and gender.

[a]DET: Detection Task; IDN: Identification Task; OCL: One Card Learning Task; CPAL: Continuous Paired Association Learning Task; GML: Groton Maze Learning Test; GMR: Groton Maze Learning Test- delayed recall

[b]DET, IDN, CAPL, GML and GMR: lower score= better performance; OCL: higher score= better performance

Figure 1 Plots (line of best fit) between the predicted values of each cognitive task (based on model one*) and the dietary patterns z- score (“Western” and “Healthy”)



Legend:
Healthy diet pattern ————
Western diet pattern - - - - - - - -

Notes

*Model 1 includes: “Healthy” and “Western” dietary pattern, total energy intake

DET: Detection Task; IDN: Identification Task; OCL: One Card Learning Task; CPAL: Continuous Paired Association Learning Task; GML: Groton Maze Learning Test; GMR: Groton Maze Learning Test- delayed recall

DET, IDN, CAPL, GML and GMR: lower score= better performance; OCL: higher score= better performance

Appendix 1 Dietary patterns and their factor loadings in the Raine Cohort at 14 years (Ambrosini et al., 2009b)

Food Group	Factor Loadings	
	'Healthy' Pattern	'Western' Pattern
Takeaway foods	-0.20	**0.53**
Confectionery	-0.14	**0.46**
Red meat	0.14	**0.46**
Refined grains	0.03	**0.42**
Processed meats	-0.02	**0.41**
Potato, fried e.g. french fries	-0.25	**0.39**
Crisps (potato chips)	-0.22	**0.39**
Soft drinks	-0.18	**0.37**
Cakes, biscuits	0.10	**0.34**
Potato, not fried	0.21	**0.34**
Sauces and dressings	0.13	**0.34**
Full fat dairy products	0.00	**0.30**
Yellow, red veg	**0.56**	0.12
Leafy green veg	**0.49**	0.00
Tomato	**0.49**	0.00
Cruciferous veg	**0.48**	0.27
Other vegetables	**0.66**	0.22
Fresh fruit	**0.48**	-0.02
Legumes	**0.43**	0.19
Wholegrains	**0.39**	-0.12
Fish, steamed, grilled or tinned	**0.33**	0.05
Poultry	0.01	0.29
Soups	0.26	0.26
Eggs	0.20	0.24
Fish, fried or battered	0.02	0.23
Added sugar	0.13	0.21
Milk dishes	0.13	0.20
Meat dishes	0.26	0.15
Canned fruit	0.26	0.11
Dried fruit	0.23	0.00
Juices	0.19	-0.02
Nuts	0.17	-0.02
Mineral water	0.23	-0.05
Low fat dairy products	0.22	-0.10
Variance	*4.28*	*2.89*
% variance	***50***	***34***
Mean	0	0
Standard deviation	0.89	0.87
Min	-2.12	-2.07
Median	-0.1	-0.13
Max	5.01	4.74

Foods having a factor loading of ≥ 30 are highlighted in bold.

Appendix 2 CogState variables explanation

CogState Tasks	Task descriptions	Main outcome measures and interpretation
Detection Task (DET)	Participants have to respond when the card is turned over	Mean of the $\log_{10}$ transformed reaction times in milliseconds for correct responses Lower score = better performance
Identification Task (IDN)	Participants have to indicate whether the card that turned over is red	Mean of the $\log_{10}$ transformed reaction times in milliseconds for correct responses Lower score = better performance
One Card Learning Task (OCL)	Participants have to indicate if they have seen the card before in the task	Arcsine transformation of the square root of the proposition of correct responses Higher score = better performance
Continuous Paired Association Learning Task Part 1 and Part 2 (CPAL)	Participants have to find the correct location of the object that match with the object in the centre	Total number of errors made on five trials in Part 1 and Part 2 (the two scores are averaged) Lower score = better performance
Groton Maze Learning Test (GML)	Participants have to find a hidden pathway within a maze	Total number of errors made on five trials to learn the same hidden pathway Lower score = better performance
Groton Maze Learning Test-delayed recall (GMR)	Participants have to remember and find a hidden pathway within a maze, as identified in the original (GML) trial	Total number of errors made on one trial Lower score = better performance

Key points

- Little is known about how diet influences cognitive development during adolescence, which is a significant developmental period for the brain.
- The findings of this study suggest that intake greater score of a "Western" dietary patter, high in take away foods, red and processed meat, soft drink and fried and refined foods, may be a risk for poorer cognition.