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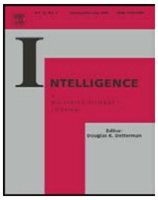

Dietary patterns and intelligence in early and middle childhood

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ABSTRACT

The association between intelligence and diet at 3.5 and 7 years was examined in 591 children of European descent. Approximately half of the children were born small-for-gestational age (birth weight ≤10th percentile). The relationship between IQ and diet (measured by food frequency) was investigated using multiple regression analyses. Eating margarine at least daily was associated with significantly lower IQ scores at 3.5 years in the total sample and at 7 years in SGA children. For all children, eating the recommended daily number of breads and cereals was associated with significantly higher IQ scores at 3.5 years, and those who ate fish at least weekly had significantly higher IQ scores at 7 years than those who did not. The consumption of fish, breads and cereals commeasurable with nutritional guidelines may be beneficial to children's cognitive development. In contrast, consuming margarine daily was associated with poorer cognitive functioning. Further research is needed to identify the nutrients that may underlie this association.

Nutrition can affect cognitive development in children. Studies have found that malnutrition (Black, 2003b; Pollitt, Saco-Pollitt, Jahari, Husaini, & Huang, 2000) and specific micronutrient deficiencies including iron, iodine, zinc and folate are associated with measures of cognitive ability (Black, 2003a; Hassing, Wahlin, Winblad, & Backman, 1999; Kretchmer, Beard, & Carlson, 1996; Lozoff, Jimenez, Hagen, Mollen, & Wolf, 2000; van den Briel et al., 2000). Most nutrition studies have been undertaken in developing countries where children are more likely to suffer from severe nutritional deficiencies, such as protein energy malnutrition. In these countries it is difficult to separate the impact of nutrition on children's development from other environmental risk factors, such as poverty and infection.

There have been fewer studies that have examined the association between cognitive functioning and dietary patterns in children from developed countries. Diets in western countries are generally considered to be adequate for growth and development (Benton, 2001), however, studies have found that some children in these countries consume inadequate amounts of micronutrients (Benton, 2001; Benton & Roberts, 1988), or suffer from food-insufficiency (Alaimo, Olson, & Frongillo, 2001). Lynn (1990) argued that nutrition was a major causal factor responsible for secular increases in intelligence in developed nations, particularly increases in visuo-spatial abilities. A study of medium to high socio-economic status children with normal or high intelligence found that higher dietary iron and folate intakes were associated with higher IQ scores (Arija et al., 2006). Morgan, Taylor, and Fewtrell (2004) also found that higher intakes of meat in infancy were positively associated with psychomotor development at 22 months of age. Experimental studies on breakfast consumption have also found that children who eat

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breakfast perform better on cognitive tasks compared to children who do not (Pollitt, Leibel, & Greenfield, 1981; Pollitt, Lewis, Garza, & Shulman, 1982; Rampersaud, Pereira, Girard, Adams, & Metzl, 2005). However, these improvements on cognitive tasks may be restricted to children who are undernourished (Pollitt, Cueto, & Jacoby, 1998).

In recent times studies have focused on the association between cognitive functioning and macronutrients such as protein and fats. A study of nearly 4000 US children aged between 6 to 16 years of age found that higher intakes of polyunsaturated fatty acids (PUFAs) were associated with better performance on a short-term memory task (digit span), while higher intakes of cholesterol were associated with lower scores on the same task (Zhang, Hebert, & Muldoon, 2005). In a study of 500 Finnish children (Rask-Nissila et al., 2002) higher intakes of PUFAs were found to be associated with better visual motor skills, and higher intakes of protein were associated with speech and language skills. This study did not, however, control for potential confounders such as parental socioeconomic status.

Overall, there have been few studies that have examined the relationship between dietary fats and cognitive ability in children. However, a number of adult studies have found an association between dietary fats and cognitive functioning. The consumption of fish and marine omega-3 (n-3) PUFAs has been associated with better scores on measures of cognitive functioning including speed of processing (Kalmijn et al., 2004) and lower risk of dementia, Alzheimer's disease and cognitive decline (Kalmijn et al., 1997; Morris et al., 2003; Morris, Evans, Bienias, Tangney, & Wilson, 2004). In comparison, higher intakes of dietary cholesterol and saturated fats have been found to be associated with lower scores on memory tasks and cognitive flexibility (Kalmijn et al., 2004; Morris et al., 2004).

Infant nutrition studies have examined the impact of breastfeeding on cognitive development. A number of studies have found a positive association between longer durations of breastfeeding and higher intelligence scores (Oddy et al., 2003; Quinn et al., 2001). In a randomized intervention trial, Lucas, Morley, and Cole (1998); Lucas, Morley, Cole, Lister, and Leeson-Payne (1992) found that children born preterm who were fed either breast milk or preterm formula had significantly higher IQ scores in middle childhood, compared with children who were fed standard formula. Early nutrition may be particularly important for children who are born small. Recent research suggests that breastfeeding is more beneficial for cognitive development in small-for-gestational age children than children born appropriate-for-gestational age (AGA) (Rao, Hediger, Levine, Naficy, & Vik, 2002; Slykerman, Thompson, Becroft et al., 2005). However, little is known about the impact of post-infancy diet on cognition in SGA children.

The aim of this study was to examine whether dietary patterns, as measured by a semi-quantitative food frequency questionnaire (FFQ), were significantly associated with intelligence at 3.5 years and 7 years in a sample of New Zealand (NZ) European children. A second aim was to examine the association between dietary patterns and intelligence at 3.5 years and 7 years in small-for-gestational (SGA) children born at term. In this study, we examined whether IQ scores differed in relation to whether children ate in line with New Zealand nutritional guidelines (Ministry of Health, 2002). Foods rich in micronutrients associated with cognitive functioning (e.g. iron) were also examined in relation to intelligence scores.

1. Method

1.1. Subjects and general procedure

Children in this study were those enrolled in the Auckland Birthweight Collaborative (ABC) study. The ABC study is a longitudinal study based on a case–control design at birth and this study has been previously described in detail (Thompson et al., 2001). In brief, approximately half of the children in the study were born SGA, weighing less than, or equal to, the sex-specific 10th percentile for gestational age (Thompson, Mitchell, & Borman, 1994). Controls were born appropriate-for-gestational age (AGA), weighing greater than the sex-specific 10th percentile for gestational age. All children were born at term, defined as 37 or more weeks of completed gestation. SGA babies and randomly selected AGA babies born between 16 October 1995 and 12 August 1996 in the Auckland Healthcare area and Waitemata Healthcare area, and between 12 August 1996 and 30 November 1996 in the Auckland Healthcare area were eligible for inclusion in the study. In the recruitment phase, 2308 eligible singleton babies were born. Babies were excluded if they had any congenital abnormalities likely to affect growth and/or development. At birth, 1714 mothers and children enrolled in the study, of these 840 were born SGA and 877 AGA. As reported previously (Thompson et al., 2001), there were no differences found between responders and non-responders at birth in the sex distribution of the infants, the infants' gestational age at birth, or the hospital of birth. Mothers of AGA infants were more likely to take part than mothers of SGA infants. NZ European mothers were more likely to take part than non-NZ European mothers.

Ethnicity information was collected at birth in obstetric records and in the maternal questionnaire. Ethnicity in this study was based on obstetric records as reported by mothers in hospital at time of birth. At the birth phase, information was collected on 871 NZ European mothers and children (SGA = 385, AGA = 486). At 3.5 years, 550 NZ European mothers and children (SGA = 224) were interviewed. The response rate for Maori, Pacific Island and other non-NZ European participants (who did not report NZ European ethnicity) was low (19%) at 3.5 years. Analysis of the results of children in these groups was considered to be unrepresentative of children in the overall population. Subsequent analyses were restricted to NZ European participants. Ethical approval was obtained from the North Health Research Ethics Committee.

1.2. Food frequency questions

Food frequency information was collected for the children at 3.5 years and 7 years. An interviewer-administered semi-quantitative food frequency questionnaire (FFQ), examining the frequency of consumption of a wide variety of commonly eaten foods, was completed by mothers. The FFQ had been previously validated against a four day weighed food record and against biochemical measures, and showed good short-term repeatability in infants aged 6–24 months of age (Chua, 1999). The FFQ was then adapted for 3.5 year old children or 7 year old children, and was comparable to the FFQ used in the New Zealand 2002 National Children's Nutrition Survey

(Ministry of Health, 2003). The FFQ examined how often a child had eaten a certain food in the previous four-week period. The response options were (i) Never; (ii) <once per month; (iii) 1–3 times per month; (iv) 1 time per week; (v) 2–4 times per week; (vi) 5–6 times per week; (vii) once per day; and (viii) 2 or more times per day. Data collection over a two-year period allowed for the seasonal variability in intake of food in this population group.

Food frequency information on 88 individual foods or drinks was converted to times eaten per month and combined to create overall food groups (e.g. fruit). In order to convert data on foods into groups, the mid-point of the frequency options was taken for options such as, 1–3 times per month, which was calculated as 2 times per month. The percentages of children consuming the following food groups in line with nutrition guidelines (Ministry of Health, 2002) were calculated: fruit (≥2 a day); vegetables (≥2 a day at 3.5 years, ≥3 a day at 7 years); breads and cereals (including rice and pasta) (≥4 a day); meat, fish, chicken and eggs (≥1 a day); and milk and dairy products (≥2 a day) (R. F. Theodore et al., 2006). New Zealand nutrition guidelines are comparable to international dietary guidelines (British Nutrition Foundation, 2004; Center for Nutrition Policy and Promotion, 1999; Department of Health and Family Services, 1998; National Health and Medical Research Council, 2003; U.S. Department of Health and Human Services, 2005). For other food groups, the percentage of children eating from a food group daily or weekly was calculated. These food group categories were created for foods considered to be rich in nutrients that have been associated with cognitive functioning (e.g. iron, omega-3 fatty acids). These food groups included fish, 'oily' fish, margarine, butter, blended spread, and vitamin and/or mineral supplements. Fish included fish fillets (fresh or frozen, with or without crumbs), shellfish and all fish in the category 'oily' fish. 'Oily' fish included the consumption of canned tuna, dark fish (e.g. salmon, sardines) either fresh or tinned, tinned salmon and sardines in oil. Blended spreads were those that contained both margarine and butter, and this information was only collected at 7 years. Vitamin and/or mineral supplements included general multivitamins, vitamin C, iron supplements and halibut oil. Children were also divided into those who ate red meat two or more times a week and those who did not. Red meat included liver, beef/pork/lamb as part of a dish, beef/pork/lamb as main dish and corned beef.

1.3. The cognitive ability tests

Cognitive ability was assessed using Total IQ at approximately 3.5 years, measured by the Stanford–Binet Intelligence Scale — Fourth Edition (Thorndike, Hagen, & Sattler, 1986) by one of eight examiners. At the 7-year phase, children's intelligence was assessed using Full-Scale IQ (FSIQ) measured by the Wechsler Intelligence Scale for Children — Third Edition (WISC-III) (Wechsler, 1992). Verbal IQ (VIQ) and Performance IQ (PIQ) scores were also obtained. The WISC-III was administered by one of three trained examiners. At both phases, examiners were blind to children's dietary patterns and birth weight status.

1.4. Statistical analyses

Analyses were performed for the total sample of children and also the SGA children alone. Analyses for the total sample employed weighting to adjust for the disproportionate sampling of children born SGA. Simple linear and multiple linear regressions were used to estimate changes in IQ scores in relation to food groups. An independent variable that showed evidence of an association ($p \leq .10$) with IQ measures at 3.5 years or 7 years in univariate analysis, was individually entered into the multivariable model.

For the 3.5 year analysis, multiple regression analyses controlled for the following potential confounders: gestation; parity (number of previous deliveries); gender; maternal school leaving age; parental occupation; marital status; maternal Body Mass Index (BMI); children's BMI at 3.5 years and the examiner administering the Stanford–Binet. This statistical model was used previously by Slykerman et al. (2005). The multivariable model was used for the analyses of both the total sample of children and the SGA group alone. For the 7 year analysis, a main multivariable model was also created to examine the association between explanatory variables and IQ scores at 7 years. This model adjusted for gender, gestation, maternal smoking during pregnancy, maternal age, maternal marital status at 7 years, birth order at 7 years, parental occupation at 7 years, parental education at birth, children's BMI at 7 years, maternal BMI and the WISC-III examiner (R.F. Theodore et al., 2009). Evidence of a statistically significant association in multivariable analysis was defined as an overall p-value of $\leq .05$.

Analyses were carried out using proc surveyfreq and proc surveyreg in SAS v9.1.

2. Results

2.1. Descriptives

At birth, information was collected on 871 children (SGA = 385, AGA = 486) whose mothers had self-identified at enrolment as being NZ European. At 1 year, 744 (85%) NZ European mothers and infants participated (SGA = 315, AGA = 429). When the children were 3.5 years of age, 550 (63%) of the NZ European participants were assessed (SGA = 232, AGA = 318). At 7 years there were 591 respondents (68%) (SGA = 241, AGA = 350).

Total IQ scores were available for 531 children at 3.5 years. At this phase, the mean weighted Total IQ score for the total sample was 112.2. Mean intelligence test scores for SGA children (112.0) and AGA children (112.3) were not significantly different (Slykerman, Thompson, Pryor et al., 2005). At 7 years, 589 FSIQ scores were available for analysis. The weighted mean FSIQ score for the total sample was 110.1. Intelligence scores at 7 years of age for SGA children (108.6) and AGA children (110.7) were not significantly different. There were also no differences in food frequency between SGA and AGA children.

2.2. Analyses with the total sample

Estimates denoting the difference in mean Total IQ scores at 3.5 years based on food frequency categories in the total sample are shown in Table 1. At 3.5 years, eating breads and cereals four or more times per day was positively associated with intelligence with an increase of 5.34 IQ points (95% C.I.: 1.56, 9.12). After controlling for potential confounders, the mean difference in Total IQ scores for children who ate breads or cereals four or more times per day was 3.96 points (95% C.I.: 0.20, 7.60) higher than for children not consuming bread and

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Table 1
Mean differences in intelligence scores in the total weighted sample of children in relation to food groups.

	3.5 years				7 years		
		Unadjusted[a]	Adjusted[a, b]			Unadjusted[a]	Adjusted[a, c]
	n (%[a])	Mean difference (95% CI)	Mean difference (95% CI)		n (%[a])	Mean difference (95% CI)	Mean difference (95% CI)
Fruit		$p = .60$				$p = .69$	
<2 a day	177 (32%)	−0.68 (−3.24, 1.88)			200 (33%)	−0.64 (−3.80, 2.52)	
≥2 a day	369 (68%)	Ref			390 (67%)	Ref	
Vegetables		$p = .15$		Vegetables		$p = .06$	$P = .15$
<2 a day	128 (23%)	1.96 (−0.68, 4.60)		<3 a day	226 (38%)	−2.80 (−5.74, 0.14)	−2.10 (−4.94, 0.74)
≥2 a day	419 (77%)	Ref		≥3 a day	364 (62%)	Ref	Ref
Cereals and breads[d]		$p < .01$	$p = .04$			$p = .75$	
<4 a day	511 (93%)	−5.34 (−9.12, −1.56)	−3.96 (−7.60, −0.20)		573 (98%)	−1.45 (−10.37, 7.47)	
≥4 a day	36 (7%)	Ref	Ref		17 (2%)	Ref	
Fish[e]		$p = .37$				$p = .004$	$P = .01$
1 a week	180 (30%)	−1.17 (−3.70, 1.36)			183 (32%)	−4.58 (−7.66, −1.50)	−3.64 (−6.54 −0.74)
≥1 a week	368 (70%)	Ref			407 (68%)	Ref	Ref
Margarine		$p = .01$	$p = .03$			$p = .10$	$P = .30$
<1 a day	284 (52%)	3.09 (0.71, 5.47)	2.81 (0.34, 5.28)		425 (71%)	2.69 (−0.49, 5.87)	1.71 (−1.54, 4.96)
≥1 a day	263 (48%)	Ref	Ref		165 (29%)	Ref	Ref
Butter		$p = .44$				$p = .28$	
<1 a day	358 (66%)	−1.03 (−3.64, 1.58)			458 (77%)	−1.72 (−4.86, 1.42)	
≥1 a day	188 (34%)	Ref			132 (23%)	Ref	
				Blended spread[f]		$p = .10$	$P = .90$
				<1 a day	472 (81%)	−3.07 (−6.70, 0.56)	0.24 (−3.52, 4.00)
				≥1 a day	118 (19%)	Ref	Ref

Meat, chicken, eggs, fish (≥1 a day), milk and dairy products (≥2 a day), red meat (≥2 a week), 'oily' fish (≥1 a week), vitamin and/or mineral supplements (≥1 a week); vitamin and/or mineral supplements (≥1 a day), were non-significant ($p = 0.10$) in univariate analyses for the total sample and the SGA group and were not included in Table 1.

[a] Weighted to account for disproportionate sampling.

[b] Multiple regression analysis controlled for gestation, parity, gender, maternal school leaving age, parental occupation, marital status, maternal Body Mass Index (BMI), children's BMI at 3.5 years, and Stanford–Binet examiner.

[c] Multiple regression analysis controlled for gender, gestation, smoking during pregnancy, maternal age, maternal marital status, birth order, parental occupation, paternal education, maternal education, WISC-III examiner, maternal Body Mass Index (BMI), and child's current BMI.

[d] All cereals, rice, pasta, and breads.

[e] Fish fillets (fresh or frozen, with or without crumbs), shellfish, all fish under the category 'oily' fish.

[f] Spreads containing both butter and margarine.

cereals at these levels. Due to the small number of children who ate these foods four or more times per day, an additional analysis was carried out by dividing children's dietary information into how often breads and cereals were consumed each day. Increasing daily bread and cereal consumption was also associated with higher IQ scores ($p = .03$). However, this effect was no longer significant after controlling for potential confounders ($p = .20$).

Eating margarine at least daily at 3.5 years was inversely related with intelligence with a decrease of 3.09 Total IQ points (95% C.I.: −0.71, −5.47) (Table 1). After adjusting for potential confounders, children who ate margarine daily had IQ scores that were 2.81 points lower (95%C.I. −0.34, −5.28) than children who did not ($p = .03$). Both daily margarine consumption and eating breads and cereals four or more times per day remained significantly associated with Total IQ when entered together into the multivariable model.

At 7 years, weekly fish consumption was significantly associated with FSIQ in the total sample (Table 1). After controlling for confounders, children who ate fish at least weekly had significantly higher FSIQ scores than those children who did not, with a difference of 3.64 IQ points (95% C.I.: 0.74, 6.54). At 7 years, weekly fish consumption was the only food found to be significantly associated with VIQ (3.29 IQ points, 95% C.I.: 0.33, 6.25) and also PIQ scores (3.36 IQ points, 95% C.I.: 0.07, 6.65). There was evidence of a marginal association between intelligence scores at 7 years and the following food groups in univariate analyses: eating vegetables three or more times a day; daily margarine consumption; and daily consumption of blended spreads. However these associations did not remain significant after the adjustment for potential confounders.

2.3. Analyses with the SGA children

At 3.5 years, eating margarine was inversely related to intelligence in the SGA group (−3.51 IQ points, 95% C.I: −0.79, −6.23) (Table 2). This association remained significant after controlling for potential confounding variables ($p = .003$). SGA children who ate margarine at least daily had significantly lower Total IQ scores than SGA children who did not, with a difference of 4.14 IQ points. In addition, daily margarine consumption was the only food found to be significantly associated with VIQ (−4.94 IQ points, 95% C.I.: −1.06, −8.82) and also PIQ scores (−6.16 IQ points, 95% C.I.: −2.25, −10.06) in SGA children. Eating butter was positively associated with intelligence (3.26 IQ points, 95% C.I.: 0.42, 6.10), and this relationship also remained significant after adjustment for potential confounders (3.55 IQ points, 95% C.I.: 0.55, 6.55). However, when margarine and butter

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Table 2
Mean differences in intelligence scores in the group of SGA children in relation to food groups.

		3.5 years				7 years	
		Unadjusted	Adjusted[a]			Unadjusted	Adjusted[b]
	n (%)	Mean difference (95% CI)	Mean difference (95% CI)		*n* (%)	Mean difference (95% CI)	Mean difference (95% CI)
Fruit		$p=.02$	$p=.15$			$p=.34$	
<2 a day	76 (33%)	−3.45 (−6.41, −0.49)	−2.38 (−5.59, 0.83)		89 (37%)	−1.61 (−4.86, 1.64)	
≥2 a day	154 (67%)	Ref	Ref		152 (63%)	Ref	
Vegetables		$p=.68$		Vegetables		$p=.93$	
<2 a day	54 (23%)	−0.71 (−4.08, 2.66)		<3 a day	93 (39%)	0.14 (−3.13, 3.41)	
≥2 a day	176 (77%)	Ref		≥3 a day	148 (61%)	Ref	
Cereals and breads[c]		$p=.80$				$p=.03$	$p=.20$
<4 a day	215 (94%)	−0.83 (−7.10, 5.44)			231 (96%)	−7.15 (−13.42, −0.88)	−4.55 (−11.53, 2.43)
≥4 a day	14 (6%)	Ref			10 (4%)	Ref	Ref
Fish[d]		$p=.26$				$p=.06$	$p=.62$
<1 a week	80 (35%)	−1.60 (−4.40, 1.20)			77 (32%)	−3.37 (−6.82, 0.08)	0.91 (−2.74, 4.56)
≥1 a week	150 (65%)	Ref			164 (68%)	Ref	Ref
Margarine		$p=.01$	$p=.003$			$p=.003$	$p=.001$
<1 a day	122 (53%)	3.51 (0.79, 6.23)	4.14 (1.45, 6.83)		171 (71%)	5.46 (1.85, 9.07)	6.06 (2.39, 9.73)
≥1 a day	108 (47%)	Ref	Ref		70 (29%)	Ref	Ref
Butter		$p=.03$	$p=.02$[e]			$p=.39$	
<1 a day	146 (64%)	−3.26 (−6.10, −0.42)	−3.55 (−6.55, −0.55)		195 (81%)	−1.68 (−5.52, 2.16)	
≥1 a day	82 (36%)	Ref	Ref		46 (19%)	Ref	
				Blended spread[f]		$p=.01$	$p=.07$
				<1 a day	189 (78%)	−5.39 (−9.27, −1.31)	−3.78 (−7.82, 0.28)
				≥1 a day	52 (22%)	Ref	Ref

Meat, chicken, eggs, fish (≥1 a day), milk and dairy products (≥2 a day), red meat (≥2 a week), 'oily' fish (≥1 a week), vitamin and/or mineral supplements (≥1 a week); vitamin and/or mineral supplements (≥1 a day), were non-significant ($p=0.10$) in univariate analyses for the total sample and the SGA group and were not included in Table 2.

[a] Multiple regression analysis controlled for gestation, parity, gender, maternal school leaving age, parental occupation, marital status, maternal Body Mass Index (BMI), children's BMI at 3.5 years, and Stanford–Binet examiner.

[b] Multiple regression analysis controlled for gender, gestation, smoking during pregnancy, maternal age, maternal marital status, birth order, parental occupation, paternal education, maternal education, WISC-III examiner, maternal Body Mass Index (BMI), and child's current BMI.

[c] All cereals, rice, pasta, and breads.

[d] Fish fillets (fresh or frozen, with or without crumbs), shellfish, all fish under the category 'oily' fish.

[e] Butter non-significant ($p=0.26$) when entered into regression model with margarine (−3.40 IQ points, 95%C.I. −0.50, −6.30).

[f] Spreads containing both butter and margarine.

were entered together into the multivariable model, only margarine remained significantly associated with Total IQ scores (−3.40 IQ points, 95% C.I.: −0.50, −6.30). Eating fruit two or more times per day was positively associated with Total IQ, however after adjustment for potential confounders, this association was no longer significant ($p=.15$).

At 7 years, there was a significant inverse association between daily margarine and FSIQ in SGA children (Table 2). This association remained highly significant in multivariable analysis ($p=.001$). SGA children who ate margarine at least daily had significantly lower FSIQ scores than SGA children who did not, with a difference of 6.06 IQ points (95% CI: −9.73, −2.39). Daily blended spread consumption was associated with FSIQ in univariate analysis ($p=.01$). Children who ate blended spreads at least daily had significantly higher FSIQ scores compared with children who did not. This association did not reach statistical significance ($p=.07$), however, in multivariable analysis. Consumption of the following foods was found to be significantly associated with FSIQ at 7 years in univariate analyses in the SGA group, but no significant associations were detected in multivariable analyses: breads and cereals (4≥per day). There was evidence of a marginally significant positive association between weekly fish consumption at 7 years and FSIQ in SGA children ($p=.06$). This association did not remain significant, however, after adjustment for potential confounders ($p=.62$).

3. Discussion

This longitudinal study of children, followed up at pre-school and school age, examined whether dietary patterns, commensurable with nutrition guidelines, were related to cognitive ability. Foods considered to be rich in nutrients associated with cognitive functioning were also examined in relation to IQ scores. We found a number of dietary factors to be significantly and positively associated with intelligence measures, including higher intakes of breads and cereals and weekly fish consumption. In contrast, daily margarine consumption was associated with significantly lower intelligence scores, particularly in SGA children.

The association between margarine consumption and IQ scores was the most consistent and novel finding of the present study. Margarine consumption at 3.5 years was associated with significantly lower general intelligence scores at 3.5 years both in the total sample and in the SGA group. Daily margarine consumption at 7 years was also associated with significantly lower general intelligence scores at 7 years but only in SGA children. This finding is consistent with previous studies that have found that early diet may be particularly important for cognitive development in SGA babies (Rao et al., 2002; Slykerman, Thompson, Becroft et al., 2005). It also highlights the relationship between dietary factors post-infancy and cognitive development in babies born small.

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As far as we are aware, no previous study has examined the effect of margarine consumption on cognitive functioning. Therefore these results should be interpreted with some caution. Furthermore, potential mechanisms underlying the association between margarine and IQ are unclear. However, associations between daily margarine consumption and intelligence scores were found at both 3.5 years and at 7 years of age in SGA children and remained significant after controlling for potential confounders.

In order to examine whether it was the characteristics of the children who ate margarine that underlie the association found between margarine consumption and intelligence, a supplementary analysis of daily margarine consumers was performed. This analysis found a poor to moderate association between consuming margarine daily at 3.5 years and at 7 years in the SGA group (Kappa = 0.33) and the AGA group (Kappa = 0.29). Therefore those children consuming margarine daily at 7 years were a relatively different group compared with those children who ate margarine daily at 3.5 years.

One possible mechanism that may underlie the association between daily margarine intake and intelligence is trans fatty acids or hydrogenated fats. In developed countries, margarines often contain trans fatty acids (Albers et al., 2008; Skeaff, Gowans, Skeaff, & Gowans, 2006) and studies have found that levels of these fats are inversely related to product price (Albers et al., 2008; Ricciuto, Ip, & Tarasuk, 2005). Trans fatty acids have been associated with poorer cognitive performance in adults (Morris et al., 2004). Studies on rats have also shown an association between hydrogenated fats and poorer memory performance (Granholm et al., 2004). Trans fatty acids may also impair the metabolism of long-chain polyunsaturated fatty acids (LCPUFAs), and maternal pregnancy trans fatty acid intake has been inversely associated with LCPUFAs levels in infants at birth (Mojska, 2003). LCPUFAs are one proposed mechanism thought to underlie the positive association between breastfeeding and intelligence (Caspi et al., 2007). In addition, some studies have found that infants, in particular preterm infants, fed formula containing LCPUFAs have improved cognitive development compared with infants fed formula that does not contain LCPUFAs (Birch, Garfield, Hoffman, Uauy, & Birch, 2000; Lucas et al., 1998; Lucas et al., 1990).

In this study, eating fish at least weekly was found to be associated with significantly higher general intelligence scores at 7 years in the total sample of children, thus supporting earlier reports of a positive association between fish intake and cognitive outcomes (Daniels, Longnecker, Rowland, Golding, & Alspac Study Team, 2004; Kalmijn et al., 2004; Morris et al., 2003). Fish contains a number of nutrients that have been associated with cognitive functioning. For example, fish is a good source of protein, bioavailable iron, zinc, vitamin B-12 and iodine (National Health and Medical Research Council, 2003). Seafood is also a good source of vitamin B-12, iron and zinc. Importantly, fish provides a rich source of omega-3 PUFAs, although the content of these fats is dependent on the type of fish that is eaten.

Eating breads and cereals four or more times a day was associated with significantly higher general intelligence scores at 3.5 years. IQ scores of children who ate breads and cereals at least four times a day were nearly four points higher compared with children who did not eat breads and cereals at these levels. Due to the small number of children who ate breads and cereals in line with nutrition guidelines, these results need to be interpreted with some caution. In relation to the long-term effects of these foods, higher intakes may result in higher intakes of iron and folate, and breads and breakfast cereals were found to be the main sources of iron and folate for New Zealand school-aged children (Ministry of Health, 2003). Bread and cereals are also carbohydrate-rich foods that are good sources of energy and may impact on children's cognitive ability, behavior and ability to learn (Gibson & Michael, 2002; Korol, 2002; Lieberman, 2003). The consumption of these foods may also lead to short-term effects on cognitive performance, particularly low glycaemic index cereals (Ingwersen, Defeyter, Kennedy, Wesnes, & Scholey, 2007).

Potential limitations of this present study need to be addressed. One limitation was that analyses were restricted to New Zealand European families, due to the lower participation rates of non-NZ European (e.g. Maori and Pacific Island) families at the 3.5 year assessment phase. Only one previous NZ study has examined ethnic differences in intelligence scores (Fergusson, Lloyd, & Horwood, 1991). However, this study found that intelligence scores did not differ according to ethnicity if appropriate social and environmental factors were controlled for in analyses. A second limitation of the present study was that NZ European mothers who participated at the 3.5 year and 7-year assessment phases had higher socio-economic status (e.g. occupation, education levels, marital status) compared with NZ European mothers who did not participate (Slykerman, Thompson, Pryor et al., 2005). Therefore the loss to follow-up was selective. Due to the potential selection bias in this study, the estimates presented are likely to be conservative. A third limitation of this present study was the use of only one measure of children's diet. The FFQ used in this study only examined food frequency in the previous four-week period, however, FFQs are considered to be good measures of long-term diet and are appropriate for use in large epidemiological studies (Willett, 1990). However, nutrient intakes were not examined in this present study, and further research is needed to examine the nutrient composition of the foods found to be associated with children's intelligence (e.g. margarine). Furthermore, it was not possible to examine the amount of the foods that were consumed. Finally, this study is cross-sectional and does not prove causation. Therefore, the association between diet and IQ was examined at 3.5 years and then at 7 years. Further research is needed to examine the long-term impact of food frequency on later IQ.

There were a number of strengths of the present study. Firstly, this sample contained a large number of children born SGA. This allowed for the investigation of dietary patterns that were associated with intelligence in the SGA group alone. In addition, the use of statistical weighting enabled for the examination of factors associated with intelligence in the total sample children. Most nutrition studies have focused on children under 2 years of age (Bryan et al., 2004). A second strength of this study was the assessment of intelligence during both early and middle childhood.

In summary, a number of foods were found to be significantly associated with measures of children's intelligence. Higher intakes of breads and cereals, and weekly fish consumption, were associated with significantly higher intelligence scores, with increases in IQ of nearly four points. Current nutrition guidelines encourage the regular consumption of these types of food. Daily margarine consumption was associated with significantly lower

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intelligence scores, particularly in SGA children. Children who ate margarine daily had IQ scores that were up to six points lower compared to children who did not. The impact of regular margarine consumption on intelligence now warrants further investigation in order to replicate these findings and to identify possible mechanisms that may underlie this association.

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