The Impact of Diet on Cognition

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The Modern, Western-Type Diet

• Modern, ‘junk food’ diets are seriously damaging our physical health – leading to increased rates of:
  – Obesity
  – Type-II Diabetes
  – Heart Disease
  – Cancer
  – Allergies / Immune Disorders

• Diet also affects our brains and behaviour

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Psychological / Psychiatric Disorders

Schizophrenia
Depression
Bipolar Disorder
Anxiety Disorders

Diagnoses are descriptive – based on behaviour, not etiology
Conditions are dimensional – i.e. continuous with normal function
Comorbidity is high, adding to heterogeneity within each

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The Shape of Things to Come

The Economist, Dec 11 2003

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Childhood behavioural and learning difficulties – the Overlap

Dyslexia
ADHD
Dyspraxia
Autistic Spectrum

• These diagnoses are descriptions – they are not explanations.
• Difficulties are dimensional, affecting > 20% of UK school children

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The role of Nutrition?

• Appropriate nutrition is essential for:
  – The growth and development of brains and bodies
  – Building, maintaining, fueling and repairing every cell in every part of the brain and body

• At least 39 essential nutrients must be provided by our food
  – These include vitamins and minerals, essential amino acids, and omega 3 and omega 6 fatty acids

• Many of these are lacking from modern diets
• Individual differences affect dietary requirements
  – Specific nutrients may be needed in unusually high quantities
  – There may be allergies or intolerances to certain foods

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**Nutrition and Antisocial Behaviour**

(Gesch et al, 2002 Brit. J. Psychiat.)

- Randomised controlled trial of dietary treatment
- 231 young offenders imprisoned at a high-security unit in the UK took part
- Each received either a multivitamin + fatty acid supplement, or a matched placebo

Could diet help to reduce violence and cut crime?

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**Gesch et al 2002: RESULTS**

All Disciplinary Incidents - Intent to treat (ITT) = 231.

1133 offences: Active vs Placebo: -26.3% (p < 0.027)

Supplementation for at least 2 weeks: Active vs Placebo: -34.0%

And for violent offences only: -37.0%

**The unbalanced diet…**

Many nutritional features of modern western diets are both evolutionarily novel and pathological

- High Glycaemic Load
- Altered Fatty Acid Composition
- Altered Macronutrient Composition
- Reduced Micronutrient Density
- Acid-Alkaline Balance
- Sodium-Potassium Ratio
- Dietary Fibre

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**The Human Brain is 60% FAT and it matters what kind**

Is the Changing Fat Content of our Diets Changing our Minds?

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**The absolute essentiality of Omega-3 DHA (and Omega-6 AA) for brain development**

Professor Michael Crawford, Imperial College School of Medicine, London
Founder, Institute of Brain Chemistry and Human Nutrition, London

1970s: gave warning to W.H.O. and governments: “Brain Disorders will be next”
Why Might Omega-3 be Important for Child Behaviour and Learning?

- Theoretical Rationale?
  - Long-chain omega-3 play critical roles in brain development, brain structure & brain function
- Evidence of Association?
  - Epidemiological studies
  - Clinical and experimental studies
- Evidence of Causality?
  - Randomised Controlled Trials

Importance of Omega-3 fats for brain development and function

- Omega-3 were only recognised as essential nutrients in the 1960s
- The long-chain omega-3 (EPA and DHA) are critical for normal structure and function of the brain and nervous system

‘Dietary shifts’ following industrialisation

\[ \uparrow \text{vegetable oils, } \downarrow \text{seafood intakes} \]

have reduced tissue levels of long-chain omega-3

Changes in Dietary Fat Intake

Omega-6 / Omega-3 Ratio – Dramatic Increase

EFA content of breastmilk of US women 1945-1995

Long-chain Omega-3 (and Omega-6) Fats are Essential for Healthy Brain Development

97% of the Omega-3 in the Brain is DHA

‘Functional Fats’: Conversion of Omega-3 and Omega-6 to Regulatory Substances

Why we need Omega-3 LC-PUFA (1)
1. For the normal structure of cell membranes
   - DHA (and omega-6 AA) increase membrane fluidity, essential for optimal cell signalling
   - 6-10% of the brain should be DHA
   - DHA is particularly concentrated at synapses, where chemical signals between cells are exchanged

   - Dopamine, serotonin and other brain signalling chemicals are influenced by omega-3 status

Why we need Omega-3 LC-PUFA (2)
1. For the normal structure of cell membranes
   - Omega-3 (and omega-6) increase membrane fluidity, essential for optimal cell signalling

2. Brain development
   - Omega-3 and Omega-6 LC-PUFA make up around 20% of dry brain mass, and affect brain growth and connectivity
   - DHA and AA are preferentially transferred via the placenta, and are found in breastmilk (so are important in infant formula)

DHA accumulation in brain in early life

Martinez, 1991
Maternal Omega-3 DHA deficiency impairs synapse development

Adequate DHA  Deficient in DHA

Synapses in Hippocampal Neurons


Omega-3 and Vision

Omega-3 fatty acids from fish oils are absolutely essential to the visual system
- 30-50% of the retina should be made of the omega-3 DHA
- At the earliest stages of visual processing, DHA deficiency can reduce retinal signalling to 1/1000 normal levels.
- Omega-3 deficiency is associated with poor night vision and other problems with visual, spatial and attentional processing.

Why we need Omega-3 LC-PUFA (3)
1. The structure of all cell membranes
   - Omega-3 (and omega-6) increase membrane fluidity, essential for optimal cell signalling
2. Brain development
   - Omega-3 and Omega-6 LC-PUFA make up around 20% of dry brain mass, and affect brain growth and connectivity
   - DHA and AA are preferentially transferred via the placenta, and are found in breastmilk (so are important in infant formula)
3. Maintenance of optimal brain function throughout life
   - Cell signalling depends on membrane fluidity
   - Omega-3 and omega-6 LC-PUFA and their derivatives influence almost all brain signalling systems
   - They also profoundly affect hormonal balance, blood flow and immune system function

Evidence of Association

Epidemiological and Experimental Studies

Maternal Seafood Intake During Pregnancy and Child Developmental Outcomes

Evidence from the ALSPAC ‘Children of the ‘90s’ study


Do the Benefits of Consuming Fish and Seafood in Pregnancy outweigh the Potential Risks?

Child’s Verbal Intelligence (IQ) at 8 years


r = 0.97
r² = 0.95
F = 27.2
p < 0.02.
Evidence for fatty acid abnormalities in ADHD, Autism, Dyslexia and related conditions

Blood biochemical studies
- Relative deficiencies of long-chain omega-3 (EPA/DHA)
- Elevated omega-6/omega-3 ratio – especially AA/EPA (an index of inflammatory tendencies)
- Increased oxidative stress / lipid peroxidation
- Enzyme abnormalities consistent with increased loss of omega-3 / omega-6 fatty acids

DHA Enhances Frontal Functioning in Boys

**Design**
- Healthy boys age 8.10 (n=33)
- Randomised into 3 groups
- 400 mg DHA, 1,200 mg DHA, placebo
- 8 weeks duration
- fMRI at baseline and 8 weeks during CPT

**Results**
- greater DLPFC activation from 0-8 weeks in omega-3 groups vs controls
- higher blood omega-3, higher middle + inferior frontal activation, faster reaction times

UK - General School Population
The DHA Oxford Learning And Behaviour (DOLAB) Study

Low blood Long Chain Omega-3 fatty acids in UK children are associated with poor cognitive performance and behavior

DOLAB Study – Screening stage
Healthy children aged 7-9 years from mainstream schools, selected for below-average reading at age 7

Measuring Blood Fatty Acids
- Innovative method of collecting blood samples
- Ethically acceptable
- Objective measure of fatty acids – superior to subjective reports of food intake
The ‘Omega-3 Index’

- In adults, % EPA+DHA in red blood cells is a well-validated index of cardiovascular disease risk

<table>
<thead>
<tr>
<th>Omega-3 index (EPA + DHA)</th>
<th>Low risk</th>
<th>High risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12%</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td>0%</td>
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</tbody>
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Mean for UK children 2.46%

Children’s reported fish consumption?

- Almost 9 / 10 of these children ate fish less than twice a week.*
- 9% did not eat fish at all
- * UK Dietary guidelines = 2 portions of fish a week

DHA and Reading ability* (n = 493)

Children with higher blood DHA were better readers (rho= 0.114, p < 0.01)

DHA and Working Memory* (n = 493)

Children with higher blood DHA had better working memory (rho= 0.141, p < 0.002)

DHA and ADHD-type Symptoms (n=402)*

Higher blood DHA status was associated with fewer attention and behaviour problems (parent-rated)

- Oppositional (rho = -.16, p < 0.001)
- Hyperactivity (rho = -.12, p < 0.012)
- Anxiety (rho = -.12, p < 0.018)
- Psychosomatic (rho = -.15, p < 0.002)
- Global Restless-Impulsive (rho = -.11, p < 0.032)
- Global Emotional Lability (rho = -.17, p < 0.001)
- Global Total Index (rho = -.14, p < 0.007)
- DSM-IV Hyperactive-Impulsive (rho = -.13, p < 0.007)

*Conners Parent Rating scales (CPRS-L)

Blood DHA and Children’s Sleep


Children with lower blood DHA had more sleep problems (rho= -0.11, p < 0.05)
Evidence of Causality

Randomised Controlled Trials

Dysfunctions of Body and Mind that Omega-3 from Fish and Seafood can help to prevent or ameliorate

- Cardiovascular Disease
  - Heart Disease and Stroke
- Inflammatory / Auto-immune Disorders
  - e.g. Rheumatoid Arthritis
- Visual Problems
  - ‘Retinopathies’ of Prematurity, Diabetes, Old Age
- Disorders of Behaviour, Learning and Mood?
  - Depression and other mental health problems
  - ADHD / Dyspraxia / Dyslexia etc

ADHD symptoms

Treatment effect sizes 0-3 months


Global scales

(Mean change / Baseline SD)

Conners’ Total
Restless-Impulsive
DSM Inattention

DSM Hyperactivity

Reading and Spelling


Active treatment

- Compared with expected progress for normal children, gains were > 3 x normal rate for reading, > 2 x for spelling

Placebo

- Gains were 1 x normal rate for reading, < 0.5 x for spelling

Group Differences

- Reading p < 0.004
- Spelling p < 0.001

THE OXFORD-DURHAM STUDY:

A randomised controlled trial of dietary supplementation with fatty acids in children with developmental coordination disorder.


117 underachieving children aged 5-12 years from mainstream schools

- All showed specific difficulties in motor coordination (DSM-IV DCD)
- 40% were behind expected achievement in reading and spelling
- Over 30% scored in the clinical range for ADHD-type symptoms (>2SD above population means)
**Reduction in ADHD-related Symptoms**

- DSM Combined-type
- DSM Hyperactivity
- DSM Inattention
- Conners Global Index
- CG Emotional Lability
- CG Restless-Impulsive
- Conners Index
- Social Problems
- Perfectionism
- Anxiety
- Hyperactivity
- Cognitive Problems
- Opposition

**Omega-3 from fish oils are effective in reducing ADHD symptoms**

- **Placebo (N=52)**
- **Active (N=50)**

**What About the General School Population?**

**The DHA Oxford Learning And Behaviour (DOLAB) Study**


**DOLAB Study – Basic Design**

**Randomised Controlled Trial:**

- Population:
  - 360 healthy, normal children aged 7-9 years
  - Normal ability, but reading < 20th 33rd centile
- Treatment:
  - Algal DHA (600mg/day) or placebo for 16 weeks:
- Primary outcomes:
  - Reading
  - Behaviour (ADHD-type symptoms)
  - Working Memory
- Secondary outcomes:
  - Sleep
  - Blood fatty acids

**Reading**

% Increase in Reading Age


- Lowest 33% of readers
- Lowest 20% of readers
- Lowest 10% of readers

% Reading Age Increase for DHA over placebo

ADHD Symptoms (1)


- Change Scores for CPRS-L (Sub-Scales)
- Whole Sample (n=362)

Effect of DHA on Sleep


- 40% of children (n=188) had clinical-level sleep problems according to parent ratings (Child Health Sleep Questionnaire, CHSQ)
- In these children, DHA supplementation (600mg/day for 16 weeks) significantly improved their sleep (CHSQ Total Sleep Disturbance Scores)

Actigraphy - Gives an Objective Measure of Sleep

- Watch-sized device
- Worn on non-dominant hand or ankle
- Used for 5 days for better measurement
- Complemented by parents' report sleep diary.

Children receiving DHA vs Placebo gained 58 minutes more Sleep


- Total Minutes of Sleep
- Changes in Minutes of Sleep

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Learning is easier when your brain is well fed... and well rested!

Dietary need for Omega-3 (EPA/DHA)

International scientific organisations recommend:
- General population (cardiovascular health): > 500mg/day EPA+DHA\(^1\)
- Depression or other mental health conditions: > 1000mg/day EPA+DHA

Most developed countries, typical intakes < 150mg/day (less for children)

\(^1\) APA Freeman et al 2006, Hibbeln & Davis 2009

More Good Reasons to Eat Fish and Seafood

- Other key nutrients in fish and seafood are very important for brain function, such as:
  - Selenium
  - Iodine
  - Zinc
  - Vitamin D
  - B Vitamins

Nutrition in disorders of behaviour, learning and mood – other issues

1. Blood sugar regulation problems?
2. Micronutrient deficiencies or imbalances?
3. ‘Anti-nutrients’ and toxicity issues?
4. Food allergies or intolerances?
5. Enzymes / gut flora
6. ‘Leaky gut’ problems / malabsorption?

SUMMARY

- Long-chain Omega-3 (EPA and DHA) are essential for brain development and function - but dietary intakes are very low in most developed countries
- Blood DHA% directly relates to behaviour and learning
  - in children with ADHD and in the general population
- Dietary supplementation with Omega-3 LC-PUFA can improve behaviour and learning
  - in children with ADHD and related conditions
  - in healthy but underperforming children from the general school population

Further Information

For details of this and related research see

Food And Behaviour Research
www.fabresearch.org

and the book
‘They are what you feed them’