

# Dark adaptation, motor skills, docosahexaenoic acid, and dyslexia<sup>1,2</sup>

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**ABSTRACT** Dyslexia is a widespread condition characterized by difficulty with learning and movement skills. It is frequently comorbid with dyspraxia (developmental coordination disorder), the chief characteristic of which is impaired movement skills, indicating that there may be some common biological basis to the conditions. Visual and central processing deficits have been found. The long-chain polyunsaturated fatty acids (LCPUFAs) are important components of retinal and brain membranes. In the preliminary studies reported here, dark adaptation was shown to be impaired in 10 dyslexic young adults when compared with a similar control group ( $P < 0.05$ , repeated-measures analysis of variance); dark adaptation improved in 5 dyslexia patients after supplementation with a docosahexaenoic acid (DHA)-rich fish oil for 1 mo ( $P < 0.05$ , paired  $t$  test on final rod threshold); and movement skills in a group of 15 dyspraxic children improved after 4 mo of supplementation with a mixture of high-DHA fish oil, evening primrose oil, and thyme oil ( $P < 0.007$  for manual dexterity,  $P < 0.02$  for ball skills, and  $P < 0.03$  for static and dynamic balance; paired  $t$  tests). The studies were small and had designs that did not allow firm conclusions to be made. However, when considered with other evidence from another closely related condition, attention-deficit hyperactivity disorder, for which reduced ability to elongate and desaturate the essential fatty acids linoleic acid and  $\alpha$ -linolenic acid to arachidonic acid and DHA, respectively, has been proposed, the studies suggest that more research, including double-blind, placebo-controlled studies, would be useful to clarify the benefits of LCPUFAs in dyslexia and other closely related conditions. *Am J Clin Nutr* 2000;71 (suppl):323S–6S.

**KEY WORDS** Dyslexia, dyspraxia, developmental coordination disorder, long-chain polyunsaturated fatty acids, dark adaptation, docosahexaenoic acid, vision

## INTRODUCTION

The British Dyslexia Association (1) defines and describes dyslexia as follows: "Dyslexia is a complex neurological condition which is constitutional in origin. The symptoms may affect many areas of learning and function, and may be described as a specific difficulty in reading, spelling and written language. One or more of these areas may be affected. Numeracy, notational skills (music), motor function and organisational skills may also be involved. However, it is particularly related to mastering written language, although oral language may be affected to some degree." Dyslexia is a common condition and may be becoming more prevalent, though it is unclear whether the

increase is genuine or reflects better identification. It has been estimated from government-sponsored studies in the United Kingdom and the United States that 10% of these populations suffer to some extent from dyslexia and that 4% are severely affected. In the United States there was a 3-fold increase in the prevalence of learning disabilities between 1976 and 1993, and 80% of those with learning disabilities are dyslexic (2). In 1993, the European Dyslexia Association estimated there are  $\geq 15$  million Europeans with dyslexia (1). Much of the difficulty in assessing the true prevalence of dyslexia arises out of the confusion about the definition of dyslexia. In fact, some even deny it exists. Because dyslexia can be such a disabling condition, personal and public concern is rising. It not only poses great difficulties for the individual but also has broad economic and social implications because of the associated significant loss of human potential.

The major features accepted by most as characteristic of dyslexia are unexpected difficulty with learning to read and write, left-right directional confusion, mirror reversals of letters and words, problems with remembering sequences such as multiplication tables and the alphabet, and poor short-term memory. The reading impairment in dyslexia is associated with poor phonologic processing, in which the sounds of syllables are broken down into phonemes, the smallest acoustically distinguishable components of speech. Learning to read unfamiliar words by breaking them down into phonemes before interpreting their meaning requires accurate auditory perception and frequency analysis, which appear to be a problem in dyslexia. However, dyslexic individuals also have difficulty with short, familiar words of one syllable that are usually recognized visually as a whole, suggesting that there is impairment of visual processing as well. Some features of dyslexia overlap with those of 2 other developmental disorders, attention-deficit hyperactivity disorder (ADHD) and dyspraxia (developmental coordination disorder). Distractibility, poor attention, and impulsive behavior are features of both ADHD and dyslexia. The essential feature of dyspraxia is a marked impairment in the development of motor coordination to the extent that the impairment significantly interferes with academic achievement or activities of daily life (3). Children

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with this disorder have difficulty with handwriting, balance, and ball skills. In the British Birth Cohort Study, which included >17000 children, predictors for dyslexia were examined by using logistical regression techniques. Of the 43 variables with statistically significant binary associations with dyslexia, 6 survived the procedure. The “failing to catch a ball” test—which involves throwing a ball up, clapping a specified number of times and catching it—predicted dyslexia (4). This indicates that motor coordination problems, the core feature of dyspraxia, are a major feature of dyslexia as well. These 3 disorders tend to run in families, indicating a strong genetic component and a possible common element in the genetic predisposition. Autoimmune disorders, allergies, autism, and schizophrenia are also associated in the families with developmental disorders, suggesting a common biological basis to the syndromes (5). This common biological basis may be related to fatty acid metabolism because disorders of fatty acid metabolism, clinical features of essential fatty acid deficiency, and improvements with specific fatty acid supplements have been reported in all of these conditions.

### VISUAL PROCESSING IN DYSLEXIA

There has been some debate about the role of visual factors in dyslexia. Rapid visual stimuli are processed by the magnocellular transient system, and there is anatomical (6), psychophysical (7), and functional magnetic resonance imaging (8) evidence that this system is impaired in dyslexia. Magnocellular ganglion cells receive input from all cone cell types and from rod cells and have large receptive fields (9). They are important for motion detection. Rod cells in particular are important for vision in light of low intensity, ie, dark adaptation. In rod cell outer segments docosahexaenoic acid (DHA) is a major constituent of the membranes and accounts for  $\leq 50\%$  of all fatty acids, depending on the phospholipid class (10). Synaptic membranes are similarly enriched with DHA, suggesting an important role for this fatty acid in neurotransmission (11, 12). Because there are indications of visual and central processing deficits in dyslexia, it seems pertinent to investigate fatty acid metabolism and requirements in this condition.

In a previously reported study (13), rod function was measured in 10 young adults with dyslexia and 10 control subjects with a Friedmann Visual Field Analyser 2 (Clement Clarke International Ltd, Harlow, United Kingdom) set for the dark adaptation function. Poorer dark adaptation was found in the dyslexic group ( $P < 0.05$ , repeated-measures analysis of variance) (Table 1). In another study (13) dark adaptation was tested in 5 young adults with dyslexia and 5 control subjects before and after supplementation for 1 mo with high-DHA fish oil providing 480 mg DHA/d. There was no change in dark adaptation in the control group. Once again, we found that dark adaptation in the dyslexic subjects was poor. After supplementation, however, scotopic vision was consistently and significantly improved ( $P < 0.05$ , paired  $t$  test on final rod threshold) (Table 2). Poor dark adaptation may be associated with poor vitamin A status. In both studies, 7-d food records (in household measures) were completed and vitamin A intakes were estimated by using food-composition tables. There was no evidence of inadequate dietary supply of vitamin A nor was there a significant difference in intakes between the dyslexic and control groups. Seven-day food consumption records are not ideal for estimating vitamin A intakes, but it was thought that the dyslexic group in particular was less likely to complete longer food records satisfactorily. Interestingly, one of the control subjects in the sup-

**TABLE 1**

Dark adaptation in young adults with dyslexia and nondyslexic control subjects<sup>1</sup>

Time (min)	Control subjects (n = 10)	Dyslexic subjects <sup>2</sup> (n = 10)
	<i>density units</i>	
1	0.18 ± 0.21	0.10 ± 0.17
2	0.42 ± 0.29	0.36 ± 0.40
3	0.67 ± 0.39	0.50 ± 0.36
4	0.80 ± 0.53	0.62 ± 0.36
5	0.84 ± 0.26	0.74 ± 0.54
6	1.04 ± 0.34	0.82 ± 0.58
7	1.18 ± 0.50	1.00 ± 0.60
8	1.36 ± 0.66	0.94 ± 0.60
9	1.49 ± 0.71	1.06 ± 0.67
10	1.71 ± 0.72	1.36 ± 0.74
11	1.96 ± 0.55	1.30 ± 0.78
12	1.98 ± 0.74	1.42 ± 0.68
13	1.93 ± 0.59	1.36 ± 0.75
14	2.04 ± 0.64	1.52 ± 0.75
15	2.18 ± 0.53	1.68 ± 0.66
16	2.40 ± 0.45	1.72 ± 0.65
17	2.40 ± 0.57	1.90 ± 0.61
18	2.49 ± 0.54	1.80 ± 0.60
19	2.60 ± 0.40	1.94 ± 0.48
20	2.49 ± 0.47	1.94 ± 0.48

<sup>1</sup> $\bar{x} \pm SD$ .

<sup>2</sup>Significantly different from the control group, (repeated-measures ANOVA)  $P < 0.05$ .

plementation study, a vegetarian, had poor dark adaptation at the outset that improved after supplementation. The low DHA content of his diet may have contributed to his condition. These are preliminary studies and it is vital that they are extended with double-blind, placebo-controlled trials of fatty acid supplementation in dyslexic subjects. Such studies are in progress.

### MOTOR SKILLS

We investigated the effect of supplementation with certain fatty acids on motor skills in dyspraxia. This condition is frequently comorbid with dyslexia. The parent members of a local group affiliated with the Dyspraxia Foundation (Hitchin, United Kingdom) invited us to test their children before and after supplementation with a mixture of n-3 and n-6 fatty acids. Seventeen families volunteered for the study. Written, informed consent was obtained from the parents and children. All children completed the baseline assessments but 2 failed to attend the final assessment. Eleven boys and 4 girls aged 5–12 y completed the study. Motor skills were assessed using the ABC Movement Assessment Battery for Children (14). The test consists of 2 parts: a checklist, completed by an adult familiar with the child, and a series of objective measures of motor skills to assess manual dexterity, ball skills, and static and dynamic balance. The checklist was completed by a parent and examines the complex interactions between the child and the physical environment. It can be used on a single occasion to screen a child with problems or, as in this study, before and after a treatment to evaluate the treatment effects (14). The movement tests can also be used to evaluate treatment effects. The test battery was completed at the outset and after 4 mo of supplementation with a patented mixture of tuna oil, evening primrose oil, thyme oil, and vitamin E (Efalex; Efaamol

**TABLE 2**

Dark adaptation in young adults with dyslexia and nondyslexic control subjects before and after supplementation with high-docosahexaenoic acid fish oil for 1 mo<sup>1</sup>

Time (min)	Control group (n = 5)		Dyslexic group (n = 5)	
	Before supplementation	After supplementation	Before supplementation	After supplementation
	<i>density units</i>			
1	0.2 ± 0.20	0.1 ± 0.12	0.2 ± 0.28	0.2 ± 0.14
2	0.3 ± 0.30	0.3 ± 0.18	0.5 ± 0.25	0.4 ± 0.22
3	0.5 ± 0.36	0.4 ± 0.22	0.6 ± 0.17	0.7 ± 0.18
4	0.6 ± 0.36	0.5 ± 0.36	0.8 ± 0.47	0.8 ± 0.32
5	0.8 ± 0.48	0.4 ± 0.36	1.0 ± 0.61	1.0 ± 0.26
6	0.9 ± 0.58	0.6 ± 0.51	0.9 ± 0.60	1.2 ± 0.47
7	0.9 ± 0.58	0.7 ± 0.63	1.1 ± 0.67	1.2 ± 0.52
8	0.9 ± 0.58	0.7 ± 0.63	1.0 ± 0.70	1.4 ± 0.51
9	1.1 ± 0.59	0.9 ± 0.67	1.2 ± 0.67	1.5 ± 0.50
10	1.4 ± 0.76	1.0 ± 0.78	1.3 ± 0.64	1.5 ± 0.44
11	1.5 ± 0.73	1.1 ± 0.76	1.5 ± 0.76	1.9 ± 0.36
12	1.6 ± 0.75	1.1 ± 0.64	1.5 ± 0.72	1.8 ± 0.39
13	1.8 ± 0.71	1.9 ± 0.73	1.8 ± 0.62	1.9 ± 0.42
14	1.9 ± 0.70	2.0 ± 0.62	1.7 ± 0.60	2.0 ± 0.45
15	2.0 ± 0.57	2.0 ± 0.58	1.8 ± 0.56	2.0 ± 0.43
16	2.3 ± 0.41	2.0 ± 0.54	1.8 ± 0.44	2.2 ± 0.36
17	2.4 ± 0.40	2.2 ± 0.55	1.9 ± 0.50	2.2 ± 0.30
18	2.4 ± 0.40	2.3 ± 0.48	1.9 ± 0.46	2.4 ± 0.26
19	2.4 ± 0.40	2.4 ± 0.41	2.0 ± 0.46	2.4 ± 0.26
20	2.4 ± 0.40	2.4 ± 0.41	2.0 ± 0.46	2.4 ± 0.26 <sup>2</sup>

<sup>1</sup> $\bar{x} \pm SD$ . There were no significant differences in the control group before and after supplementation.

<sup>2</sup>Significantly different final rod threshold from before supplementation,  $P < 0.05$  (paired  $t$  test).

Ltd, Guildford, United Kingdom). The supplement provided 480 mg DHA, 35 mg arachidonic acid, 96 mg  $\gamma$ -linolenic acid, 80 mg vitamin E, and 24 mg thyme oil daily. Thyme oil is a volatile oil extracted by steam distillation from the herb thyme and is rich in antioxidants, including thymol and carvacrol (15, 16). The study was open and no placebo was used. The test battery used was developed to establish the efficacy of treatment interventions devised by physical education professionals and occupational therapists when it is not possible to blind the child, the parent, or the therapist to the nature of the intervention.

At the outset, all children had checklist scores above the 15th percentile, indicating marked difficulty in movement. This was confirmed by the objective measures of movement performance (Table 3). For the total impairment score, derived by summing the scores for manual dexterity, ball skills, and static and dynamic balance, 14 children exceeded the first percentile and 1 child, age 12, was in the 8th percentile. High

scores indicate poor performance. Manual dexterity, ball skills, and static and dynamic balance were poor at baseline and improved after supplementation (Table 3). Overall total impairment scores and checklist scores improved significantly after supplementation (Table 3, Figure 1, and Figure 2). The variation in response between individuals is shown clearly in Figures 1 and 2.

There is much interest in providing adequate amounts of long-chain polyunsaturated fatty acids to fetuses, premature infants,

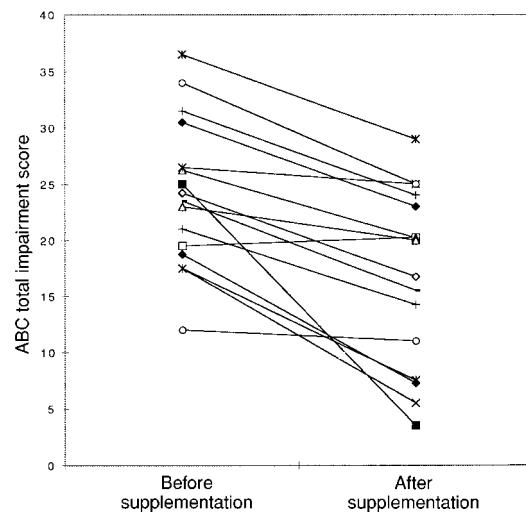
**TABLE 3**

ABC Movement Assessment scores in dyspraxic children before and after 4 mo of supplementation with n-3 and n-6 fatty acids<sup>1</sup>

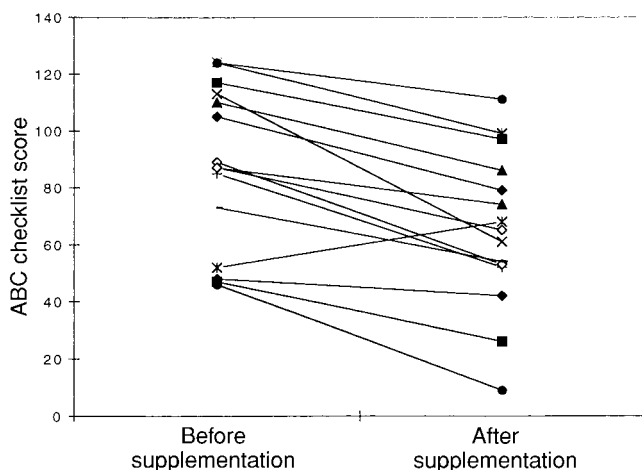
Test	Before supplementation	After supplementation	Paired $t$ test $P$
Manual dexterity	9.93 ± 2.85	6.95 ± 3.76	< 0.007
Ball skills	6.03 ± 2.94	3.90 ± 2.13	< 0.002
Static and dynamic balance	8.23 ± 4.47	5.88 ± 4.09	< 0.03
Total impairment score	24.20 ± 6.83	16.73 ± 8.16	< 0.0001
Checklist score <sup>2</sup>	87.14 ± 29.61	65.07 ± 28.63	< 0.001

<sup>1</sup> $\bar{x} \pm SD$ ;  $n = 15$ . High scores indicate poor performance.


<sup>2</sup>Records incomplete for one child;  $n = 14$ .



**FIGURE 1.** ABC total impairment scores (summation of scores of objective tests for manual dexterity, ball skills, and static and dynamic balance; 14) in 15 dyspraxic children before and after supplementation with long-chain polyunsaturated fatty acids.



**FIGURE 2.** ABC checklist scores (an assessment of the child's day-to-day motor functioning completed by the parent; 14) in 14 dyspraxic children before and after supplementation with long-chain polyunsaturated fatty acids.

and full-term infants, as is discussed in detail elsewhere in this supplement. The studies described above showed that there may be some value in providing long-chain polyunsaturated fatty acid supplements to older children with specific learning disorders. It was shown that boys with ADHD have clinical and biochemical signs of essential fatty acid deficiency and that these children may be less able to convert the essential fatty acids linoleic acid and  $\alpha$ -linolenic to their long-chain derivatives, arachidonic acid and DHA, respectively (17). Overall academic achievement and mathematical ability was found to be significantly better in boys with high  $n-3$  fatty acid concentrations than in boys with lower  $n-3$  fatty acid concentrations (18). Behavior also appears to be related to  $n-3$  fatty acid status in monkeys (19) and in boys (18). If individuals with dyslexia and dyspraxia have poorer conversion of linoleic acid to arachidonic acid and of  $\alpha$ -linolenic acid to DHA, it is not surprising that supplements providing arachidonic acid and DHA appear to help. The studies described earlier are preliminary, small, and have design faults that do not allow firm conclusions to be made. Further studies, including double-blind, placebo-controlled trials, are in progress to verify the value of fatty acid supplements in dyslexia, ADHD, and dyspraxia. The mechanisms underlying the relations among academic achievement, learning disorders, behavior patterns, and motor skills require detailed examination. 

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