In comparing brain development in different species of animals, the focus needs to be on the total amount of DHA/AA available to the animal (whether derived preformed or by metabolism from LA/LNA) because the proportions of the fatty acids are very similar in the brains of all species. Is the size of a herbivore's brain, which is smaller than a human being's, limited by availability of LCPUFA? I am not alone in rejecting this idea (Pond & Colby, 1990).

Many present-day human beings (and presumably many latter-day individuals also) are strict vegans. It is not immediately apparent that such people are intellectually inferior to their omnivorous counterparts. The authors have not cited evidence to support such a difference and I am unaware of any such evidence. Likewise, for many years of the 20th century in industrialized countries, generations of human babies have been reared primarily and often exclusively on infant formulas that contain minute quantities, if any, of LCPUFA. Is there documentation to demonstrate that such babies developed into adults who were or are intellectually inferior to their primarily breast-fed counterparts? The authors may wish to make a distinction between availability of LCPUFA as an evolutionary driving force over a million or so years and their availability to present-day individuals who are genetically programmed to have a larger brain than other species. Nevertheless, for the individual, the problem of accumulating sufficient LCPUFA to fulfil that potential must still apply.

When one looks at herbivores such as cows, one is struck by the impressive way in which the animal conserves its precious stock of essential fatty acids (EFA), not just in the brain but in all membranous structures of its large body. Huge amounts of EFA are accumulated despite this animal's apparently suicidal habit of destroying a large proportion of its dietary intake of EFA by hydrogenation in its rumen. During evolution it has adapted so as to conserve whatever EFA is available. It should not be surprising that *H. sapiens*, in whom wastage due to biohydrogenation does not occur, is even more successful in such conservation. Furthermore, even though desaturation and elongation may be inefficient, they may be active enough to ensure that, in combination with efficient conservation, supplies meet needs. Might it not be that other environmental pressures provided the driving force for brain size development in *H. sapiens* and that mechanisms for conservation of the necessary LCPUFA adapted to cope with this increased size?

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Dietary lipids and evolution of the human brain – Reply by Broadhurst et al.

In his letter, Professor Gurr all but rejects our concept that prolonged access to a rich dietary source of long-chain polyunsaturates (LCPUFA) was a central feature of human brain evolution (Broadhurst *et al.* 1998). Instead, he favours an explanation involving 'other environmental pressures' but provides no suggestions as to what they would be. He complains about a 'worrying tendency to cite references to conference proceedings' but goes on to cite a book review about an earlier, broader discussion of diet and human evolution (Crawford & Marsh, 1989) as his only evidence to justify his hesitancy; surely if we are in 'disputed territory', there would be a few peer-reviewed publications in addition to a book review to establish that dispute.

The concept proposed by Crawford & Marsh (1989) was that limited availability of two LCPUFA, docosahexaenoate (DHA; 22:6*n*-3) and arachidonate (AA; 20:4*n*-6), places severe constraints on early brain development, and probably was a significant determinant of human brain evolution. Later, we extended this concept to include the potential importance of trace elements and energy availability and proposed that a shore-based environment rich in shellfish was probably sufficient to accommodate the nutritional requirements for human brain evolution; initially, fishing would not have been possible nor was it necessary (Cunnane *et al.* 1993). In the present review (Broadhurst *et al.* 1998), we focus on the plausibility of the Rift Valley providing not only the paleoanthropological and geological evidence but also the nutritional/ecological evidence in a fresh-water, proto-oceanic environment. We also try to link this evidence to modern nutritional studies to provide a viable explanation for the emergence of human intellectual capacity and its ongoing vulnerability.

We concede that the term 'brain-specific nutrition' is ambiguous. No nutrients are truly brain-specific; even DHA is more specific to the eye than to the brain. The term emerged from recognizing that (i) the growing brain is especially sensitive to the supply of LCPUFA, (ii) unlike other organs, the brain does not accumulate appreciable quantities of 18-carbon PUFA, and (iii) the brain is vulnerable to the absence of other nutrients such as Zn, Cu, I and Fe that are involved in PUFA metabolism; like LCPUFA, abundance and bioavailability of Zn, Cu and I are greater from fish, shellfish and meat than from terrestrial plants.

The effectiveness of desaturation and chain elongation of 18-carbon PUFA is an important component of the hypothesis; why, indeed, should DHA availability be so limiting when, even in humans, the brain only represents 2% of body weight? First, the brain actually represents 15% of human body weight at birth, so it is a much more important target for DHA in neonates than in adults. Second, as we briefly alluded to, there is general agreement that most organs including the brain have the capacity to make DHA so the issue is whether this capacity is sufficient. If, as has been done in many studies, one isolates the microsomal fraction of brain, and provides an excess of the relevant co-factors over a short time course, desaturation of a radiolabelled substrate such as α-linolenate (ALA; 18 : 3*n*-3) can readily be demonstrated, but does this mimic the situation in the intact animal? That is harder to demonstrate, especially in humans, but we cited a paper showing that a DHA deficit occurs in the infant brain if DHA is not provided in a milk formula (Farquharson *et al.* 1992). Nevertheless, DHA can be produced by the human infant (Carnielli *et al.* 1996) so the real issue is sufficiency of this pathway.

As we cited, even under the best conditions, ALA is readily β-oxidized to respiratory CO_2, especially if the animal is energy-deprived or has an unreliable energy supply as is commonly the case in the wild (Broadhurst, 1997). Furthermore, recent studies in different models of early mammalian development show that carbon from dietary ALA is recycled into saturates, monounsaturates and cholesterol in amounts that exceed that going into DHA (Cunnane *et al.* 1994; Sheaff Greiner *et al.* 1996). Impaired peroxisomal chain shortening, i.e. Zellweger syndrome, has disastrous effects on human brain development that can at least partially be overcome by direct provision of dietary DHA (Martinez, 1994). Hence, efficiency of desaturation and chain elongation is only part of the issue; for several reasons, it seems far simpler for 'Nature' to have relied on an abundant source of dietary DHA rather than on a convoluted biosynthetic pathway requiring appropriate amounts of several co-factor nutrients to make sufficient DHA.

We agree with Professor Gurr in supposing that, besides LCPUFA, there were undoubtedly 'other environmental pressures' affecting human evolution and we discussed some of them (pp. 8–12) but, first, we think it is crucial to distinguish between pressures and opportunities; we believe that human brain evolution occurred in response to an environmental/dietary opportunity; the genetic programming was there to be exploited only in the appropriate environment and some hominids including *H. sapiens* exploited this environment while other hominoids did not. We believe that human brain evolution did not, indeed could not, occur under pressure. If such pressures exist and influence brain evolution, why did only certain hominids respond? Greater intellectual capacity would be a benefit to many animal species.

The emphasis on LCPUFA in our review may seem narrow-minded but, to us, the point is that LCPUFA are such a crucial part of optimal mammalian brain function and are a logical place to start in trying to account for superior intelligence in *H. sapiens*. We agree with Professor Gurr that if availability of LCPUFA was a central feature of human brain evolution, impaired availability of LCPUFA, particularly DHA, should have detrimental consequences for brain function. The evidence for this in experimental models is widespread and documented in our review and elsewhere. We agree that the evidence in humans is controversial because most controlled studies have used healthy, term infants. Term infants are nourished through a longer period of intrauterine growth and usually have relatively large fat stores at birth from which some LCPUFA can be derived if they are not present in the milk formula.

Professor Gurr raised the issue of intelligence in vegans because of the absence of DHA in vegan diets. The purpose of our paper (Broadhurst *et al.* 1998) was to try to account for the transition from precursor hominids to *H. sapiens* and not to draw upon arguments that would compare present-day intellectual capacity of populations choosing different subsistence patterns including veganism. We made it clear that hominoid and hominid evolution diverged over a long time frame; 'rapid brain expansion' required at least one million years and modern *H. sapiens* is thought to have arisen 100 thousand–300 thousand years ago. Before the Neolithic Revolution, vegan diets were not a long-term option short of starvation conditions. Paleoanthropologists have documented that agriculture arose of necessity and was associated with declining health, height, and nutritional status in comparison to previous hunter–gatherer diets (Cohen & Armalegos, 1984; Eaton *et al.* 1996; Broadhurst, 1997). Present-day vegans are at risk for both trace element deficiencies affecting PUFA metabolism (Kadrabova *et al.* 1995), and impaired neurological and physical development of their children (Dagnelie *et al.* 1994). Furthermore, 70% of the world's blindness occurs in inland or highland areas of the largest vegetarian society in Asia but the coastal areas tend to be spared.

In any event, vegans are a limited model for assessing the relationship between DHA availability and brain development because the pregnant or lactating vegan is still transferring LCPUFA to the fetus/neonate during the most crucial period of brain development. If we are really to establish the role of DHA in human brain performance, the more relevant and vulnerable example of potential DHA deprivation is the preterm infant with all its complications, not the least of which is establishing a set of reference parameters for appropriate post-gestational development. The preterm infant has a much greater risk of impaired sensory and neurological development (Crawford *et al.* 1997) and we would argue that this risk arises in part from impaired ability to accumulate sufficient DHA.

During fetal and early postnatal brain growth, herbivores are non-ruminants so the hydrogenation of polyunsaturates that occurs later probably has little or no impact on DHA availability to the brain. However, herbivores, particularly bovids, provide a useful example of DHA being preferred for neurological membranes despite a much greater abundance in the body of the *n*-6 LCPUFA analogue to DHA, docosapentaenoate (DPA; 22 : 5*n*-3); if DHA were a non-specific membrane component for brain or photoreceptor development it could have been replaced by DPA, but this has not occurred in any species that has been studied thus far.

In conclusion, we appreciate the opportunity to clarify some of the issues surrounding this concept and hope this discussion will lead to lines of scientific enquiry that will help prove or disprove whether nutrition was a driving force behind human brain evolution.

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