of 1.0 *Pseudocalanus* female per liter, well below saturating prey concentrations. Predation rates would be higher if prey patches were considered.
17. Estimated from the population model of F. Argentesi, R. de Bernardi, and G. di Cola [*Mem. Ist. Ital. Idrobiol.* **31**, 245 (1974)], applied from 30 July to 8 August 1979. Stage durations from J. Vidal [*Mar. Biol.* **56**, 135 (1980)]. Copepodid stage abundances determined approximately weekly in summer from two or three replicate vertical hauls with a 73-μm mesh net.
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22. Electivity measures the similarity between prey composition in a predator's diet and that in the environment. Electivity index is the logarithm of Q [J. Jacobs, *Oecologia* **14**, 413 (1974)]. Ambient zooplankton abundance determined with a 216-μm, 1-m diameter net hauled vertically from 0 to 5 m (four replicates).
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Accumulation of D-Aspartic Acid with Age in the Human Brain

Abstract. *An age-related accumulation of D-aspartic acid was detected in the white matter of ten normal brains from individuals aged 30 to 80 years. Gray matter showed no systematic increase in D-aspartic acid. The rate constant for D-aspartate formation in the brain is equal to the predicted value calculated for 37°C. Accumulation of the uncommon D-aspartate isomer in myelinated white matter implies that there is little or no turnover of this tissue, and this may have a bearing on dysfunction of the aging brain or on other diseases of myelin.*

The degree of racemization (conversion) of amino acids from the biologically common L configuration to the uncommon D configuration has been correlated with the age of fossil proteins in ocean sediments (*1*) and in archeological bones and shells (*2*). The observation that aspartic acid undergoes racemization and accumulation in the stable protein of living tooth enamel (*3*) and dentine (*4*), as well as in the eye lens nucleus (*5*), led to the prediction that racemization should correlate with aging in any metabolically "stable" protein in warm-blooded animals (*6*).

Because myelin proteins in nerve tissue are relatively stable, with slower turnover than those of other proteins (*7*), we believed that racemization might be detectable in nerve tissue protein during the human life span and that aspartic acid in the white, myelin-rich, inner portion of human brains should racemize and accumulate in proportion to the age of an individual. D-Aspartic acid accumulates in human tooth enamel and dentine at a rate of about 0.1 percent per year (*3*, *4*) and in human eye lens nucleus at about 0.14 percent per year (*5*). We now report that D-aspartic acid accumulates at a similar rate in the white, myelin-rich, inner core of human brain.

Human brains obtained from subjects who had no history of abnormal pathology were frozen immediately after autopsy and were kept frozen until analyzed. White (myelin-rich) matter was separated from nonwhite (gray) tissue by dissection from the inner portion of the brain. The dissected fractions were homogenized in cold 10 percent trichloroacetic acid to precipitate the protein. The protein samples were hydrolyzed at 100°C for 6 hours in 6*N* HCl, followed by purification and isolation of aspartic acid by ion-exchange chromatography (*8*). *N*-Trifluoroacetyl-L-prolyl-D,L-aspartic acid methyl esters (volatile diastereomeric dipeptides) were synthesized, and the ratio of the amount of D-enantiomer to that of L-enantiomer (D/L) was determined on a gas chromatograph (Perkin-Elmer Sigma 2) fitted with a nitrogen-phosphorus detector and a 15-m fused-silica capillary column containing SE-54 as the bonded phase (J&W Scientific).

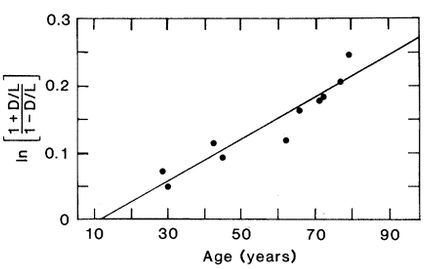

Fig. 1. Relationship between age and the ratio of D- to L-aspartic acid in the white matter of ten normal human brains.

The D/L value for laboratory-induced racemization was 0.016, which does not significantly alter the results reported.

The results of aspartic acid analyses for the white matter samples of ten normal brains were plotted (Fig. 1); a least-squares fit of the data resulted in the kinetic equation

$$\ln\left[\frac{1 + D/L}{1 - D/L}\right] = [(3.14 \pm 0.38) \times 10^{-3}]t - 0.036 \quad (1)$$

where t is the age of the individual. The data are presented in the form of a reversible first-order rate equation (*9*) rather than the irreversible equation used for the enamel and dentine results (*3*, *4*), D-aspartic acid being present in sufficient concentration in the brain to make the use of the irreversible first-order rate equation invalid. The slope of the line represented by Eq. 1 corresponds to $2k_{Asp}$, where k_{Asp} is the rate of formation of D-aspartate in the brain. Thus, in the white matter, $k_{Asp} = 1.57 \times 10^{-3}$ year^{-1} compared with the calculated value for k_{Asp} at 37°C (body temperature) of 1.50×10^{-3} year^{-1}. Analyses of eight gray matter samples by the same procedure did not show any correlation of D/L values with age.

Bada and Helfman (*2–6*) proposed the use of the D- to L-aspartic acid ratio to estimate the age of long-lived animals. We tested the possibility of a similar estimate in the human brain by analyzing a sample that was of unknown age when received. Analysis produced a D/L value of 0.0826, indicating an age of 64 years. The actual age was subsequently found to be 66 years, in good agreement with the experimentally determined value.

McFadden and Clarke (*10*) reported that all of the methylated aspartic acid isolated from erythrocyte membrane and cytoskeletal proteins has the uncommon D configuration, suggesting the presence of a system of widely distributed enzymes that recognize racemized aspartyl residues for subsequent repair. Our discovery that D-aspartic acid accumulates with age in the white matter of human brain might indicate that the McFadden and Clarke repair mechanism fails to penetrate or to function in the white matter or that there is little or no metabolic turnover of the proteins in white matter. The fact that there is no systematic increase in D/L values for aspartate in gray matter implies a far more rapid turnover or a functioning repair mechanism in this portion of brain tissue.

The line in Fig. 1 represents the best straight line fit to the data. However, data are lacking for the younger age

range, and the line may in fact curve in this region, giving a positive y-intercept instead of the negative y-intercept implied in the figure. If racemization of aspartic acid is an age-related phenomenon, and in view of the smaller amounts of aspartic acid in immature brain tissue (*11*), it is reasonable to assume a slower accumulation of the D-enantiomer during maturation and a faster accumulation during aging.

In their studies on the eye lens nucleus, Helfman *et al.* (*5*) suggested that the presence of D-aspartyl residues in proteins would alter the native conformation of these proteins and thereby also affect the biochemical and physiological functionality of these proteins. Pirie (*12*) showed that the proportion of water-insoluble protein in human eye lens nucleus increases with age, and the increase is more marked in cataracts than in normal lenses of age-matched controls. Harding (*13*) showed that proteins in cataractous lenses have a greater susceptibility to tryptic digestion, thus demonstrating that conformational changes occur during cataractogenesis.

We believe that the progressive accumulation of D-aspartic acid in the protein present in the white matter of human brain tissue may be correlated with biochemical and conformational changes that might affect the functionality of the brain. Such a finding could have important implications for age-related dysfunctions associated with the inner brain or with other myelin-related diseases. Analysis of brains with abnormal pathologies associated with senile brain dysfunctions such as Alzheimer's disease, Huntington's chorea, Parkinson's disease, or multiple sclerosis, as well as brains from victims of drug or alcohol abuse and heavy-metal poisoning, may show a relationship between the presence of these pathologies and D-aspartate levels.

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Morphological Correlates of Differences in Pheromone Sensitivity in Insect Sensilla

Abstract. *Scanning electron microscopy and single unit recordings of male* Trichoplusia ni *antennae reveal at least two classes of pheromone-sensitive sensilla trichodea. The longer sensillum contains two receptor neurons each with small amounts of spontaneous activity. One neuron responds to large (10-microgram) doses of* (Z)*-7-dodecenyl acetate, a component of the female sex pheromone. The shorter sensillum contains two receptor neurons both with larger amounts of spontaneous activity and increased sensitivity to low (0.01-microgram) doses of pheromone.*

The functional capabilities of sensory receptor neurons are ultimately determined by intrinsic surface membrane properties that account for the neurons' ability to detect particular environmental energies and extrinsic properties that serve to couple the sensory neuron to appropriate external stimuli. All of the intrinsic and extrinsic components of an adult olfactory sensillum arise from a single mother cell in the larval imaginal disk (*1*). We sought to determine in a single defined class of sensilla if the precise cell lineage patterns characteristic of development in olfactory sensilla might lead to distinctive morphological markers for differences in physiological properties.

Separate morphological and electrophysiological studies in a range of different insect species led us to suspect that, even in a restricted subset of the available olfactory sensilla, we would encounter a variety of differences among individual sensilla (*2*). Therefore, to relate a sensillum's particular morphology with the physiological properties of its receptor neurons, we examined individual sensilla electrophysiologically and labeled them unambiguously for subsequent morphological examination. We restricted our investigations to the sensilla trichodea on the antennae of the male cabbage looper (*Trichoplusia ni*, Hübner). These olfactory sensilla have long (15 to 60 μm) cylindrical cuticular shafts that taper apically from a socket diameter of approximately 2 μm. Each is innervated by two primary olfactory receptor neurons whose dendrites fill the lumen of the shaft and whose axons project, without synapse, to the deutocerebrum (*3*). These receptor neurons are specialized to respond to the pheromones produced by the female moth and are thought to provide the sensory input that allows the male to detect and locate the female. Usually the two olfactory receptor neurons within the sensilla trichodea can be differentiated from each other by the amplitudes of their action potentials, with the cell producing the larger spike designated A and the cell producing the small spike designated B.

Standard techniques were used to record extracellular action potentials from individual neurons (*4*). Stimulus application, action potential discrimination, and data analysis were accomplished with a minicomputer (*5*). Light microscopy ($\sim \times 600$) was used to determine both the sensillum from which recordings were to be obtained and the exact placement of the electrodes. After electrophysiological responses to a range of stimuli were acquired, a map of the surface of the antenna was sketched, and adjacent sensilla and scales were removed from the segment with the microelectrode. This produced a distinctive surface pattern that allowed subsequent identification of the recorded sensillum with scanning electron microscopy (SEM). Each sensillum characterized physiologically was easily identified by SEM with the landmarks created by sensilla removal (*6*).

In *T. ni*, pheromone-sensitive sensilla include at least two classes of sensilla trichodea that can be differentiated from each other by the spontaneous activity of their receptor neurons and the relative sensitivity of the neurons to pheromone (Fig. 1a). The first class has relatively high spontaneous activity (HS) averaging 1.39 impulses per second for the A neuron and 1.20 for the B neuron. The A neuron in HS sensilla is reliably excited by low doses (0.01 μg) of (*Z*)-7-dodecenyl acetate, a behaviorally active pheromone component produced by female *T. ni*. In contrast, the B neuron is reliably excited by low doses (0.01 μg) of