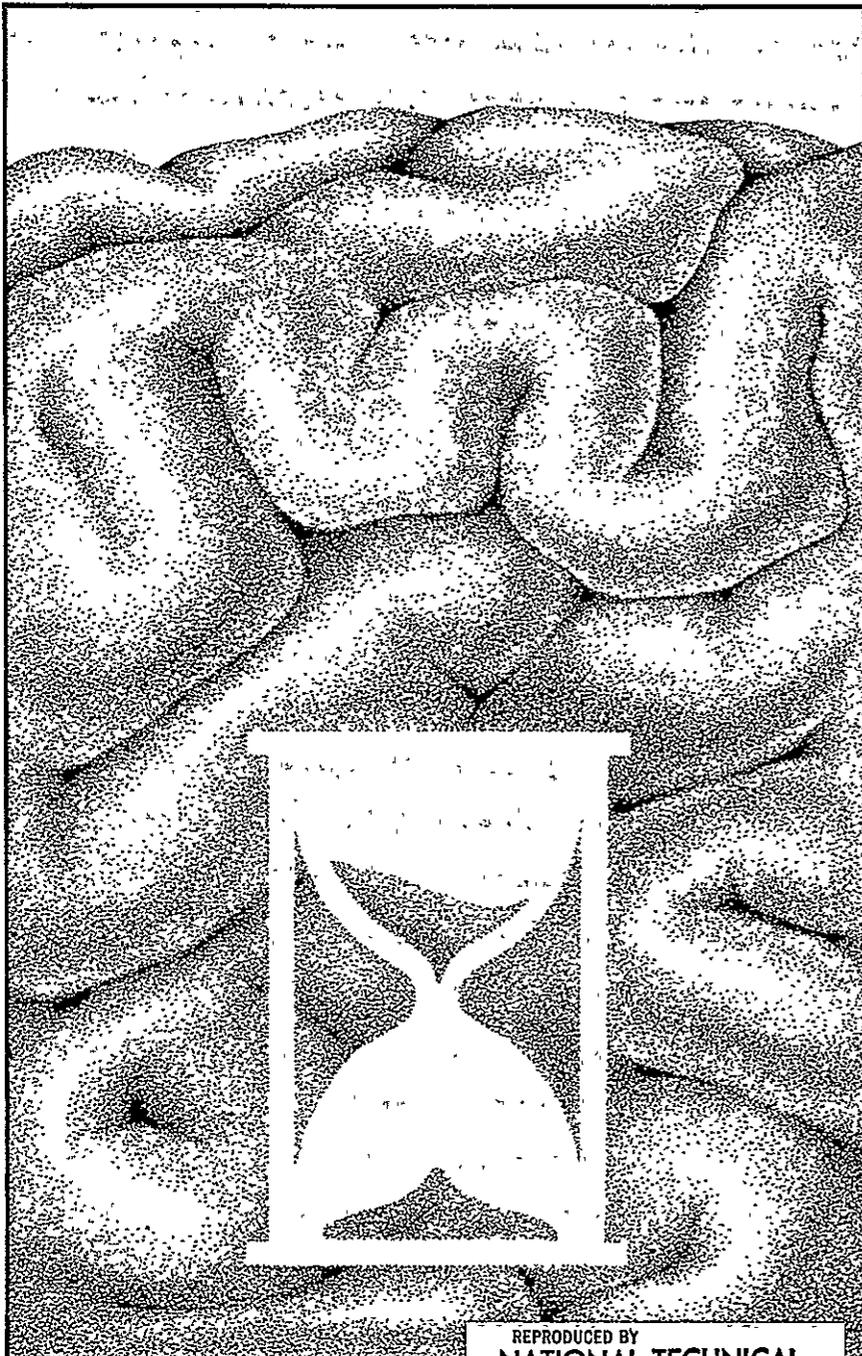


(NASA-CP-2063) HUMAN NEUROLOGICAL  
DEVELOPMENT: PAST, PRESENT AND FUTURE  
(NASA) 60 p HC A04/MF A01 CSCI 06P

N79-15887  
THRU  
N79-15897  
Unclas  
63/99 42062

# Human Neurological Development: Past, Present and Future

**ORIGINAL CONTAINS  
COLOR ILLUSTRATIONS**



Proceedings of a  
Joint Symposium  
May 18, 1978

NASA/Ames Research Center  
and  
The Institutes for the  
Achievement of Human Potential

November, 1978

**NASA**

National Aeronautics and  
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1 Report No NASA CP-2063	2 Government Accession No	3. Recipient's Catalog No
4 Title and Subtitle Human Neurological Development – Past, Present and Future. Proceedings of a Joint Symposium, May 18, 1978		5. Report Date
		6. Performing Organization Code
7 Author(s) Ralph Pelligra – editor		8 Performing Organization Report No A-7630
		10 Work Unit No
9 Performing Organization Name and Address Ames Research Center, NASA Moffett Field, Calif. 94035, and The Institutes for the Achievement of Human Potential		11 Contract or Grant No
		13 Type of Report and Period Covered Conference Publication
12 Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D.C., and The Institutes for the Achievement of Human Potential, Philadelphia, PA.		14 Sponsoring Agency Code
15 Supplementary Notes		
16 Abstract  Neurological development is viewed from the perspective of the emergence of humans from the instinct-dominated animal world to our future role as interplanetary travelers. Vision, vestibular function, intelligence, and nutrition are discussed as well as newer concepts of the treatment of perturbations of neurological function, coma, and convulsive seizures.		
17. Key Words (Suggested by Author(s)) Neurological development Coma Seizures		18 Distribution Statement Unlimited  STAR Category – 99
19. Security Classif (of this report) Unclassified	20 Security Classif (of this page) Unclassified	21. No. of Pages 69
		22. Price* \$4.50

NASA Conference Publication 2063

# Human Neurological Development: Past, Present and Future

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**Ralph Pelligra, M.D.**

**Editor**

Proceedings of a  
Joint Symposium  
May 18, 1978

NASA/Ames Research Center  
Moffett Field, California  
and  
The Institutes for the  
Achievement of Human Potential  
Philadelphia, Pennsylvania

Held at  
Ames Research Center  
Moffett Field, California



National Aeronautics and  
Space Administration

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## INTRODUCTION

Ralph Pelligra

Ames Research Center

It may seem a formidable, even impossible, task to attempt to scan 2 million years of neurological development in a 1-day symposium. Indeed, it probably would not have been possible a decade ago. Not because we have gained so much specific knowledge since then, but rather because our growing ability to accumulate, store, and disseminate great quantities of information has permitted scientists to take a more universal, interdisciplinary view of the world around them. The researcher is freer to paint his scientific canvas with broad strokes that cross many disciplines and eradicate restraints of space and time. Rapid advances in astronomy, physics, and chemistry have fostered this new perspective. Concepts of the duality of particles and waves, and matter and energy, the Big Bang, chemical evolution, the structure of DNA, and deciphering of the genetic code have all brought humans closer to the universe. We no longer need view ourselves as infinitesimal specks on an insignificant planet revolving around a minor sun in an average galaxy. It is the universe which brought us forth and which sustains us . . . it is *our* universe.

To understand human neurological organization – the process that enabled man to walk upright out of the primordial mire and onto the moon – one must draw from many disciplines and search deeply into the past and far into the future. And so it is that we have on our symposium panel educators, researchers, clinicians, *children*, and two of the greatest scientists of the twentieth century – Professors Linus Pauling and Raymond Dart. Nor is it any accident that this diverse group has chosen as its forum a NASA space center. It has been said that the need to wander through the stars is not simply a matter of cosmic curiosity; it is, in fact, a continuation of the process of evolution. Rocket ships are more than noisy machines rattling towards the heavens – they are extensions of the human mind.

## AN OVERVIEW OF THE LIFE SCIENCES PROGRAM

Joseph C. Sharp

Ames Research Center

I was happy to accept this opportunity to speak to you for a few moments about NASA's Life Sciences programs.

We have four major areas, or subdivisions, within the Life Sciences program, all of which must obviously relate to the missions NASA has been given by the Nation. The program is broad and very exciting; most of us feel it is *the* most exciting work available to modern biology and medicine.

The first major area is concerned with addressing the roles, functions, and interactions between humans and the aircraft they fly. Remember, in the acronym NASA, the first "A" stands for aeronautics. NASA's charter says we must pay attention to the aeronautical problems of the Nation. In Life Sciences, we have programs to help make aircraft and aircraft operations more efficient, safer, and more available to the public. Currently, our major efforts are toward operations of commercial aircraft.

The second area of work, for which we seem to get more publicity, has to do with maintaining life inside very small containers which are in a very hostile environment – the containers are spacecraft. NASA has a perfect record so far; we have never lost an astronaut in space. The task is very complex when one stops to think about it. Not only must we provide the obvious necessities such as air, water, and food, but also provide for management of wastes, protection from radiation, and ways to sleep and work – to mention but a few. We still must learn how to deal with the physiological changes that occur when a human is placed in an environment it has never experienced before, that is, zero gravity. All of these fall under our medical support activities. Directly related to this is the Agency's desire to open the Space Shuttle to as many people as possible. We do not want to restrict users to just a few astronauts, but to allow scientists to go and perform their experiments.

We must understand how relaxed we can be about physiological or medical deviations. For example, we want to know if travelers in the Shuttle can wear glasses, can they get by with a little hypertension, be slightly obese, be on medications, etc. We are working at delineating the medical criteria to allow normal, run-of-the-mill, hard-working people to go into space and accomplish their work.

A third area that we feel is very important is to provide the opportunity for scientists, engineers, academicians, and others to use the "space environment" to further our understanding of biological processes. If such experiments require, let's say, plants or animals, we want to have the boxes and cages to hold them – as well as the myriad tools and instruments to do the experiments. One important criteria for selecting specific experiments will be the need to go into space for the experiment. In other words, it will have to be demonstrated that the experiment cannot be done on the ground. It will be very difficult to justify experiments that ask "I wonder what will happen if . . . ?" unless there are strong hypothetical reasons to expect something unique.

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Fortunately, we have gained some very valuable experience by working out some of these problems with the Russians. We have flown both manned and unmanned experiments on their spacecraft. Some of these experiments have come from scientists here in the United States, and we have developed over the last 4 years a good working relationship. In the last 6 years, we have flown more U.S. experiments of a life sciences nature on Soviet spacecraft than we have on U.S. spacecraft. This trend will probably continue for the next few years until the Shuttle becomes operational.

We know there are medical and physiological changes in people who fly in space – we also know how to deal with most of these changes, at least for short-duration flights. We are not yet so confident that we will overcome the known problems of long-duration flights.

Finally, Life Sciences has the responsibility for the exploration for life beyond the Earth, our Extraterrestrial Biology Program. Some of you may be familiar with the Viking Program successfully completed last year. NASA landed two very complicated machines on Mars. Some of the experiments were specifically designed to test for the presence of life. These experiments were interactive and dynamic; that is, changes were made in subsequent experiments depending on data from earlier experiments. These kinds of experiments have required as complete as possible an understanding of chemical and biological evolution with an emphasis on the precursors to life. Also, an understanding of how life can and does adapt to extreme environments is a necessary component in designing experiments on other worlds as well as our ability to insure we do not contaminate the worlds we visit with our machines.

These, then, are the four major areas that NASA Life Sciences is directly involved in. We are fortunate to be working these truly new and real frontiers of our sciences. Once we were able to climb out of the hole that gravity created for us, the frontiers of knowledge and new territory became virtually unlimited. There are problems in exploiting this relatively newfound ability, but I believe we are helping to provide mankind the opportunities to go out there, to look and explore, and, possibly, to learn what life is beyond the confines of the Earth. We may even extend life as we know it to some of these other worlds.

I hope your meetings here at Ames are enjoyable and informative. I am sure we will learn from you and that maybe there are a few things we can contribute to your efforts. Thank you.

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## TECHNOLOGY UTILIZATION

Charles C. Kubokawa

Ames Research Center

Thank you very much, Ralph. I'm deeply honored to be able to speak in front of this august group to tell you a little about our Technology Utilization Program. It's rather difficult to speak about the Technology Utilization Program in the 10 minutes allocated to me, but I shall do my best to try to give you an overall picture of one of the most successful and pioneering technology transfer programs in the United States.

The Congressional Space Act of 1958 provided NASA with a charge for the widest possible dissemination of NASA information to the U.S. public. In order to act on this charge, NASA established a Technology Utilization Office in each of the 11 centers and formed three biomedical applications teams which we call the BAT teams, 3 technology application teams called the TAT teams, 9 industrial application centers, which we call the IACs, 1 technology application group, called the TAG team, and the computer software management information center, called COSMIC. The three BAT teams are located at the Research Triangle Institute in North Carolina, the University of Wisconsin, and at Stanford University. The teams are involved in work on existing physiological, medical, and rehabilitation problems.

The three TAT teams tackle the problems associated with safety, transportation, industry, manufacturing, construction, and state and local governments. They are located at Public Technology Incorporated in Washington, D.C., Stanford Research Institute, Menlo Park, California, and CAMI International in Irving, Texas.

The nine IACS, the Industrial Applications Centers, are located at the Universities of Pittsburgh, Connecticut, North Carolina, New Mexico, Southern California, Indiana, Kentucky, Oklahoma, and Florida. The network of universities has computer access to more than 8 million worldwide documents and will seek out any existing data and the state-of-the-art information on any subject of inquiry. With so many documents published throughout the world, on a daily basis, and with so many experiments being conducted, computers search systems will be used extensively in the future as a safeguard to prevent duplication or rehash of existing data. The TAG group, Informatics, is located at Baltimore. They are responsible for the dissemination of published materials to the requesters, for the documentation of all the inquiry transactions, and for the annual NASA TU progress report. I was going to bring some progress reports today, but they did not come in; if you would leave your name with me or write to me (you have my name on the program) I will be more than happy to send you *Spinoff 1978*.

NASA also provides funding for running the NASA Computer Software Management Information Center, or COSMIC, at the University of Georgia, in Athens, Georgia. The software library allows for the indexing of all computer programs generated by NASA and its contractors. COSMIC makes possible the availability of these computer programs to anyone in the United States at a nominal price. The service saves the computer-using industry millions of dollars in software programming and operational time.

The establishment of these various TU teams and programs has benefitted everyone. It has profited the U.S. taxpayers in one way or another, to the tune of 9 to 14 cents on every cent spent on NASA through the commercialization of many innovations developed through the use of NASA furnished data. A mission-oriented government agency can make major contributions by conducting experiments to learn how best to encourage the use of new knowledge generated at public expense.

I am going to show you some things that you people are probably familiar with. When we first stepped off the surface of the Earth, it gave man another perspective. We had been used to seeing the Moon rise, but now we saw the Earth rise. It also has made it possible for people to at least think about the spaceship Earth, and to realize that we must do a better job of managing our natural resources. Conservationists warn us of pollution and ecological problems, but do not realize that our amplified awareness of these problems began when we stepped off the face of the Earth.

Here is a picture of LANDSAT that is very significant to me because of the fact that in this area here it delineates the division between the United States and Mexico. It shows you that the U.S. crops are healthy, well cared for, free of insects, and well fertilized. By deciphering the redness and pinkness of some of these crops, experts can tell what kind of grain products are growing there — whether barley, corn, oats, or wheat. Here is a picture of the Sahara desert. This polygonal-shaped area on the bottom portion (let's blow it up) is an area that was never discovered before. The French government checked on it and found it to be an area in which 40 French families homesteaded for over 120 years. The straight lines are barbed wires used to keep the cattle of the nomadic tribes away from the area. In this area there is greenery and a resultant micro-climate. Here is a picture of Hurricane Camille, used in computer form. This kind of information will enable people to decipher how much water is concentrated in the hurricane, the direction it is going, its size, the heat content, etc. We have been able to take pictures from the satellites and also from low-flying aircraft, but one of the areas that we were missing data on was the middle area, so NASA purchased two U2's for Ames and other centers. We are now able to take pictures like this with infra-red photography. It's Berkeley, California, Emeryville, El Cerrito, and the University of California. You could zoom in a bit closer and decipher things like how fast the cars are going on certain roads, and *if* you could zoom in a little closer you would be able to get the license number of the car and, probably in the future, give him a ticket.

This type of information has also helped to resolve some pollution problems. The picture that you see on the left-hand side is an ordinary picture. The picture that you see on the right-hand side is an enhanced color image showing that there is actually acid and sewage dumped in areas where such dumping is forbidden. Evidence of this kind has been used in court. Here are pictures of the San Andreas fault. Note the building located directly on the fault. Information of this kind could help prevent construction on such sites.

When astronaut White went out into space, one of the things that he wore underneath his space suit was a thermal regulation garment. One of our research scientists here at Ames, Dr. Williams, was able to reduce the weight of the 60 lb Apollo thermal regulation garment to 30 lb by finding out the temperature-sensitive control areas of the body and circulating temperature-controlled liquids just to those areas. Here is what it looks like. This kind of technology has been transferred to other uses, such as the "cool head" helmet, for helicopter pilots; Richard Petty is using the helmet when driving racecars. We have also looked into the possibility of using this helmet for cooling the head portions of people going through chemotherapy. As you know, the chemotherapy used in

treating cancer can destroy the hair follicles. We have also been using this technology for looking into the possibility of locating cancer cells at a very early stage. For example, breast cooling enhances the thermography interpretation.

The astronauts have gone into space using an eye-controlled switch, so that in case they were incapacitated in space, they would still be able to actuate the switch. This eye switch has been used in controlling wheel chairs automatically. We also have gone into meal systems for the elderly. These systems are now also being used by hikers, campers, and fishermen. We have also used the Beta cloth, which is nonflammable, for firemen's uniforms and also for children's pajamas. Here are two boxes being burned each in an oil fire. The box on the right-hand side used our intumescent coating and the whole structure is free from fire.

We have elements for heating the toes in boots. Thus technology has gone into ski boots and also for heating gloves. Here is a Telecare system that telemeters the information to the hospital. We have also been involved in the end-mounted shower stalls. We have also gone into things such as lower body negative pressure to help the circulation in the extreme lower areas of the body. Here are some of the products that you people are enjoying: cushion material for the inside of football helmets, calculators, wrist watches, pacemakers, rechargeable pacemakers, even dog biscuits, packaging, the NASA Tech House which saves you over 50 percent of the water and 66 percent of the electricity normally used in a home for four persons, tennis rackets, and golf clubs.

In conclusion, I would like to say the NASA aerospace programs have been responsible for more innovations for the benefit of mankind than those brought about by either major wars, or peacetime programs. And you might wonder how much our efforts are costing you. Well, we're at the bottom of the totem pole. We are only \$3.4 billion of the annual budget. The mission of the TU program is to efficiently provide the public with expertise help and information which will expeditiously and economically facilitate the bringing about of solutions and answers to the problems or questions presented to the TU offices. In most cases, this support is provided at no cost to the public, but when working through the IACS, there will be a minimal charge for various services rendered. The TU program is to provide benefits for everyone through the secondary use of NASA-developed technologies in the most effective way possible and to prevent wasted efforts. We of all the NASA centers TU offices sincerely hope that you will use our data and facilities to enhance your research and help solve problems associated with the human neurological developments in the present and future. Thank you very much.

## WELCOMING REMARKS

Edward B. LeWinn

Institute for Clinical Investigation  
and  
World Organization for Human Potential

Good morning, ladies and gentlemen. Welcome!

On behalf of the World Organization for Human Potential I should like, first, to express to NASA/Ames Research Center and to the Institutes for the Achievement of Human Potential our deep thanks and appreciation for your co-sponsorship of this meeting, this opportunity for an exchange of ideas. Although, as listed on today's program, these ideas may seem diverse and unrelated, I assure you that you will find that they are, in fact, very closely relevant and important to all of us.

The World Organization for Human Potential is a body whose membership is made up of representatives from the various Institutes for the Achievement of Human Potential throughout the world and of many individuals who are not so affiliated. The original Institutes for the Achievement of Human Potential were founded in Philadelphia in 1955. We began with the exploration and application of new concepts in the treatment of brain-injured patients who represented the full range of causes of brain injury as well as all ages. It was soon obvious that children were crowding out the adults and so our experience has been increasingly and, in the past 16 years, exclusively with children. From the brain-injured child we learned a great deal about well children. For this reason you will hear the words "child" and "children" very frequently in the course of our part of today's program.

Let me remind you that every child at birth begins as a citizen of the world, rather than as a citizen of a specific country. The language that he speaks, although it may not seem to be a language, is in fact a language understood by mothers all over the world. It is only as cultures and customs begin to separate children that we become divided into countries and nations. Yet we are all just one large group of human beings.

Some of the work going on here at Ames Research Center illustrates this fact. I am particularly interested in Dr. Sharp's remarks concerning the interchanges in experiences and information between our astronauts and the Russians.

Mr. Kubokawa's remarks concerning the contributions being made by NASA to civilian life provide an interesting and gratifying contrast with other, less happy human activities. Much of the research and investigation in modern technology which resulted in by-products useful in civilian life came not from peacetime efforts but from war technology expensive in many terrible ways. What did it cost, for instance, for World War II to produce two important advances in medicine? Think of the urgent necessity, the cost in lives and effort that generated the very simple idea of early ambulation, breaking with tradition and getting patients out of bed and out of hospital as soon as medically feasible. Today this practice is almost universal in civilian medicine. There was a time not so very long ago when an appendectomy was thought to require 10 to 14 postoperative days in bed. Even after much more serious procedures and illnesses, patients are now ambulatory within hours or

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within a day or two. Think of what this has saved people and their communities, not only in terms of hospital costs but in prevention of debility resulting from excessive immobility. But think, too, of what it cost military establishments to learn that lesson in terms of overtaxed hospital facilities and medical personnel, of manpower lost because of excessive confinement to bed, of recuperation not only from wounds or illness but from medically-induced debility. Those were expensive lessons.

Another example was penicillin, gathering dust for some 20 years until sheer necessity during World War II motivated its rediscovery in order to supplement or supplant the sulfonamides in attempting to deal with bacterial infections.

Here at Ames Research Center there is an effective peacetime and peaceful effort which results in many products and procedures useful in everyday life. We, at the Institutes for the Achievement of Human Potential, are especially cognizant of this. I am sure that the costs of this work at NASA, which are well down toward the bottom of the list of federal governmental expenditures, is but a very tiny fraction of the cost of a World War II, or of a Korean or a Viet Nam conflict.

The World Organization for Human Potential is particularly appreciative of your efforts here at Ames Research Center in the explorations of human capabilities and potential, the area where your work and ours are so closely related. I am delighted by Dr. Sharp's invitation to employ and use your facilities with your collaboration where it seems appropriate. I can see many fields which we can explore together productively.

As I remarked earlier this week, during the first 2 days of this eleventh annual meeting of the World Organization for Human Potential in Philadelphia, the hope of the world lies in our children. Collaboration between Ames Research Center and the Institutes for the Achievement of Human Potential can result in many benefits for mankind through our children. To me it is very heartening that instead of the uses of adversity, the technological by-products of war efforts, we are today enjoying the advantages and discussing the uses of peace, of imagination, and of the best in human capability. Thank you.

## REMINISCENCES, OBSERVATIONS, AND EXPECTATIONS

Raymond A. Dart

Institute of Man, the Institutes for the Achievement of Human Potential

I need scarcely say how greatly I appreciate the privilege of having been requested to give some opening remarks at the second session of this historical meeting of The World Organization for the Achievement of Human Potential – the first to be held at the Ames Research Center, Moffett Field, California, in conjunction with members of NASA. For Marjorie and myself the opportunity of approximating so closely the scene and some of the people whose research and life-work is so intimately related with man's conquest in aerospace is a deeply appreciated occasion. Perhaps to those who have seen today Lionel Friedberg's film *The Turning Point* (ref. 1) for the first time, the occasion may be more readily recalled by the alternative title *From Australopithecus to Aerospace*, as suggested by Glenn Doman and his wife when they visited us in South Africa earlier this year.

Others cognizant of the fact that for more than a decade now we have divided our lives between Johannesburg and Philadelphia participating in the objectives of The Institutes for the Achievement of Human Potential suggested that some such general title as "Reminiscences, Observations, and Expectations" might better fit the occasion, and I am inclined to agree with them.

My life span has extended over a longer period than those of most, if not all, of my present audience, and it has been one of constant challenge. I was born, the fifth in a family of nine, in Brisbane, Queensland in Australia in the 1893 flood. There as a newly born babe, and together with my mother, we were floated out of a second-story bedroom window in an awaiting boat which took us both to safer quarters. My later childhood was spent in the country, where each morning, after milking the cows, my elder brother and I walked 2 miles thither and back from school carrying my books and luncheon. After returning home in the late afternoon the cows were again milked, the cream separated, the poultry and pigs fed. After the evening meal homework was attended before going to bed. I loved to read and loved all I learned from the family library.

Following secondary school a scholarship took me to the newly founded University of Queensland. There I took the B.Sc degree before proceeding to the University of Sydney for my medical degree in 1917.

Then, because World War I still required soldiers from the Colonies, I joined up with the Australian Army Medical Corps and set sail for England and France. After peace had been declared I settled down (as I thought) to begin a lifetime's ambition of neurological research under the late Professor (later Sir Grafton) Elliot Smith at University College in London. Here I had books, research facilities, and exciting friendships – what more could I wish? But it was not to be. In 1922, much to my chagrin I was appointed to a recently established medical school in the University of the Witwatersrand at Johannesburg in South Africa – another farflung outpost of the British Empire! So once again I packed my bags and set sail for South Africa earning my passage as ship's doctor.

Even as an Australian, who had studied in the pioneering University of Queensland I was appalled at the primitive conditions confronting me in my new post. The University itself was so

new that it possessed neither library facilities nor museum collections. I had only a scattering of medical students – the first group that graduated in 1924 numbered only four!

In my first year I was the only full-time teacher of anatomy. Facing innumerable difficulties I suggested to my students that in their July vacation they collect any bones or interesting stones which might form the nucleus of a museum in time to come. Thus it was that in the very next year one of my students – Miss Josephine Salmons – brought to me the fossil of a baboon skull. Those of you who have read *The Adventures with the Missing Link* (ref. 2, now published in paperback by our Institutes) will recall much of the happenings that followed, my excitement when two boxes of rocks arrived at my home in Johannesburg just as I was supposed to be dressing for a wedding to take place in my house. The wedding faded from my mind when I peered into the boxes and it was only when the bridegroom brought me to my senses by begging me to “hurry up and dress; as the bride was due to arrive at any minute for the ceremony.” Little did I know how those rocks with their fossils were to change my way of life again.

Then came the laborious but exciting task of exposing the fossil and digging it out slowly with the aid of my wife’s knitting needle (no diamond drills or acids to dissolve the rock-hard limestone in which it was buried). You have seen today in Friedberg’s film the little child’s skull that was eventually exposed. I had neither books to refer to for comparative sources nor museum collections to study prior to writing up my views that were founded upon as accurate measurements as I could make with the primitive tools at my disposal. On the 73rd day the “baby” was fully exposed and I was ready to write up the record for the English science journal, *Nature*.

Much of the rest of the story has been related in the film just seen. No fossil material of Early Man had come from Africa up till this time. The accepted scientific belief was that Early Man if discovered at all would eventually be found in Asia. So my discovery was not accepted for many years, nor considered seriously until more fossils came out, firstly at Sterkfontein (30 miles west of Johannesburg) where Dr. Robert Broom worked for so many years. He was the only authority who had seen my skull and he had no doubts in his mind about its place in the human story.

Rescued from his country medical practice in the depression of the 1930s, his repetitive discoveries between 1936 and his death in 1951, especially those of the complete adult skull, three brain casts, and limb and pelvic bones at Sterkfontein, Kromdraai and Swartkrans; and mine also between 1945 and 1958 with the help of my staff and students at Makapansgat some 170 miles north of Johannesburg could not be neglected. Few doubted the importance of the Australopithecines but World War II raged from 1939 to 1945 and kept medical activities elsewhere until it was over.

The most important outcome of Broom’s book, *The South African Ape-Men* (ref. 3), written in conjunction with the study of the three more brain casts by Professor G. W. H. Schepers, one of my past students and then professor of Anatomy in the new Medical School of the University of Pretoria, was the coming to South Africa of the anatomist the late Sir Wilfrid Le Gros Clark from Oxford University in England in 1946 and the conversion of both himself and Sir Arthur Keith to acceptance of the Australopithecinae as an ancestral group of ape-men. In 1938, Drs. W. K. Gregory and Milo Hellman had come to South Africa from the United States and had publicly announced their joint acceptance of *Australopithecus*, especially with regard to the dentition.

In 1948 the fraudulence of Piltdown Man was exposed publicly. It had first been suspected after Le Gros Clark's conversion (ref. 4) and Sir Arthur Keith's public apology to me by the Lecturer in Anthropology at Oxford, another of my old students – Dr. J. S. Weiner – who later published his work on *The Piltdown Forgery* in 1953.

In 1949 the Wenner Gren Foundation invited me to bring all my fossil material and reconstructions to New York for a Symposium to be attended by about 100 anthropologists. In addition I had brought an adolescent Negro pelvis with australopithecine pelvic bones inserted therein which was compared the next day directly with the pelvis of the only human African Pygmy then available in the American Museum of Natural History. So for the first time comparisons could be made between the fossil bones and the bones of Pygmies, Bushmen, and Bantu bearing out my statements in 1925 that *Australopithecus* walked upright.

In 1951 at the Cold Spring Harbor Symposium of American zoologists and anthropologists, Ernst Mayr of Harvard University swept away all the ape-men and human *species* names. *Homo* was a good *generic name* but the australopithecines had excluded the differences between anthropoids and men as separate families zoologically.

In 1959 I had become Professor Emeritus and had handed over all of my professorial responsibilities to my successor – Professor Phillip V. Tobias – another of my erstwhile students. In this same year my popular account was published as *The Adventures with the Missing Link* (ref. 2) in both England and the United States.

It was in 1958 however that the potassium argon technique of dating volcanic rocks was discovered and in the following year, Mary Leakey found the skull that was called *Zinjanthropus boisei* by her husband, Louis Leakey, at the *Fifth Pan-African Congress in Prehistory* held in Kinshasa, Zaire (then Elizabethville in the Belgian Congo).

This was most fortunate because its discovery coincided with the Centenary of Darwin's *The Origin of Species* which was held in Chicago in October and Louis Leakey was invited to exhibit it there to an entirely receptive audience of scientists in every relevant field.

After all these reminiscences and observations I feel the best I can do is to show you (on the screen) the map (see fig. 1) made and utilized by Professor Phillip V. Tobias (ref. 5) to illustrate the northern spread over Africa, firstly of the three sites initiated in 1959 in Tanzania by the late Dr. Louis Leakey and his wife Mary, of the form called *Zinjanthropus*, but now usually referred to as *Australopithecus robustus*.

On his map are the names of 16 different sites illustrating a 1975 paper published by Tobias entitled "African Cradle of Mankind." It shows in order the earliest known sites in South Africa: Taung; Sterkfontein, Kromdraai and Swartkrans nearby; and Makapansgat farther north, nearly 1000 miles from Cape Town.

The next group is over 2000 miles north of Makapansgat in Tanzania. The most important site there is Olduvai Gorge because it was the first to be dated by means of potassium argon, giving ages of nearly 2 million years for the bottom and about 1 million years for the top of the lowest stratum.

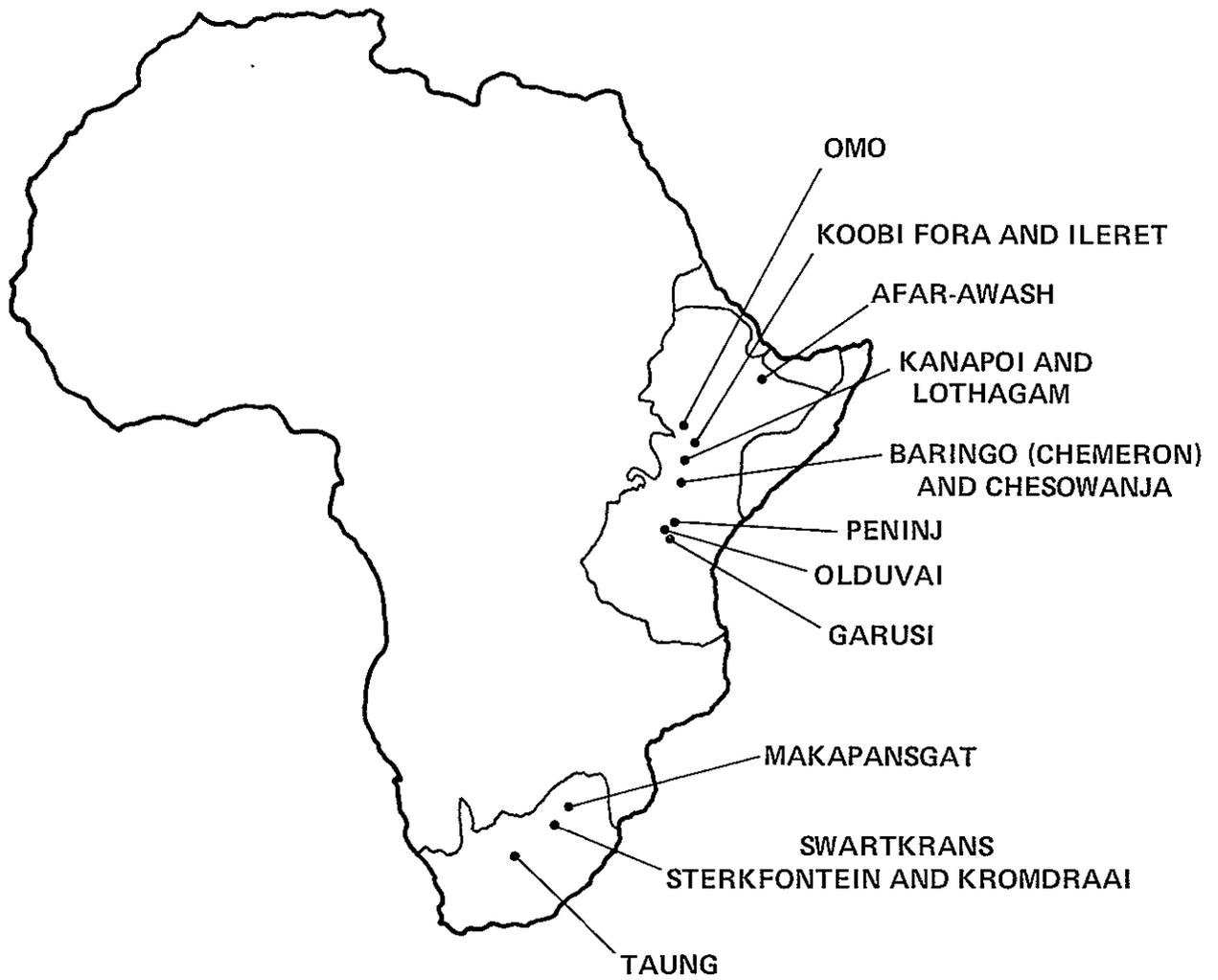


Figure 1.— African sites of early hominid discoveries.

Peninj and Garusi are two further sites in Tanzania, southeast from the vast Lake Victoria Nyanza and northeast of Lake Tanganyika. We are in the midst of the greatest split in the Earth's surface, which drains the great lakes of Africa including Lake Victoria into the Mediterranean Sea through the Nile River Valley; and whose volcanoes are still active in southwest Kenya.

There also in northwest Kenya is Lake Turkana (formerly Rudolph) into whose north flows the Omo River from Ethiopia. Hominid remains have come from no less than six sites: Baringo (Chemeron) and Chesowanja in the south of this western Kenya to Kanapoi and Lothagam near the southern end of the lake, and especially from Koobi Fora and Ileret east of Lake Turkana. There Richard Leakey (ref. 6) found in 1972 remains of the almost complete skull, which he correlates with the larger-brained hominid, because it had a brain of 750 cc and a skull with no bosses fore and aft like the gorillas and some types of mankind. So it and similar ones are called *Homo habilis* by some anthropologists.

But even though this form probably is 2 million years old the one found by Johanson at Afar-Awash in Ethiopia in 1974 and called "Lucy" is dated as over 3 million years old. Yet it resembles most closely *Australopithecus africanus* from Taung. We must also remember that Afar-Awash is not very far from the Red Sea Coast where Yves Coppens and his wife found an advanced type of *Australopithecus* near Lake Chad in Chad Territory. As Lake Chad borders on Nigeria, we already know they must have spread not only as far north in Africa as the Red Sea but also almost halfway towards its western coast south of the Sahara desert. So although more than half a century has elapsed since the first convincing specimen of human evolution was found, it is obvious that we are only at the beginning of what will become known about hominid evolution during the next millennium or two. If humanity becomes intelligent enough to survive that long and simultaneously to retain the vital knowledge and skills that science, art, common sense, and a universal language will probably have brought to all of Earth's inhabitants before the third millennium closes, there is as yet no obvious end to their combined achievements in the spatial environment that produced them.

I recall in this connection having remarked in a public lecture in Johannesburg, South Africa that it seemed to me that the only limit on what people could do was what they could imagine. That was back in 1925 or 1926. A member of the audience rose to his feet at the back of the room and protested, saying that he could imagine "a man on the moon" but that was impossible. I said that I could not imagine such a feat, but the fact that he did showed me that this fact might be nearer than we others imagined.

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N79-15890

## THE CHILD IN COMA

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### INTRODUCTION

People in coma continue to pose medical, social, economic, ethical, moral, and legal problems. Modern life-support technology has aggravated these problems. Today, vigorous and heroic action, involving the use of these complex systems, prolongs the lives of thousands of severely brain-injured human beings. However, in far too many instances following these highly laudable, heroic efforts, patients continue to exist in a vegetative state for indefinite periods with outcome uncertain while those in attendance wait for recovery of consciousness to occur spontaneously. This is true in spite of the acquisition of newer understanding of the comatose state and the development of effective procedures for its treatment at The Institutes for the Achievement of Human Potential over the past 30 years.

### DEFINITION OF COMA

Coma is difficult to define. Evidence for this fact is seen in the numerous definitions which have been composed, representing different points of view. For the purpose of these remarks we shall begin with what is probably the most commonly used definition of coma: Coma is "a state of unconsciousness from which the individual cannot be aroused, even by powerful or painful stimuli."

IAHP views coma as "a pathological state of unconsciousness from which the patient has not yet achieved arousal."

This changes the attitude toward the comatose patient from one of hopelessness and helplessness to a positive call for vigorous action to help him regain consciousness. It implies that it is still possible that the patient may be aroused, that his vanished psyche may yet be reunited with his vegetating soma.

There are two variables that have an especially important bearing on the ability to achieve arousal. These are (1) the character of the brain injury that caused the coma and (2) environmental factors that affect the patient after the injury.

### CHARACTER OF BRAIN INJURY

By the character of the brain injury we mean its cause, location, severity, and extent. Determination of these factors in the comatose child is by no means an exact science. At best it is based on

clinical estimates. In this connection we offer comments concerning two developments in recent years with regard to coma. First is the concept of identifying brain-death as the legal and medical criterion of the termination of life, regardless of continuing function of the heart, respiration, and other vital systems. The other fairly recent event is the attempt to develop a prognostic index for the comatose patient within the first few days of the onset of coma. In both situations we feel that conclusions as to death of the patient or his ability for recovery cannot be made with any degree of reliability unless he is given the trial and benefit of every possible effort to restore him to a conscious state, even when the likelihood of success in such an effort seems nil or very small. Depending solely on life-support systems, the electroencephalograph, and the dubious blessings of time constitutes an essentially passive procedure which fails to provide the patient with opportunity for adequate and persistent environmental challenges and demands for brain function.

### ENVIRONMENTAL EFFECT ON COMA

IAHP has long insisted that the young brain, even though injured to the point of coma, often reveals remarkable recuperative capabilities which are too commonly underestimated. We have repeatedly demonstrated this in children who responded to an optimal environment, highly enriched with strong, persistently repeated sensory inputs, and providing optimal blood flow carrying nutrients and oxygen in optimal concentrations.

The comatose child has been separated neurologically from his environment, thus suffering serious environmental deprivation. He is unaware not only of the world around him but of himself. In his unconsciousness he is, in fact, functionally blind, deaf, insensible to tactile stimuli and to taste and smell. Ordinary random, occasional and even sporadically intensified "powerful and painful stimuli" referred to in the definition discussed above, such as painful pressure, pin pricks, slapping, shouting in his ear, and other stimulation employed in repeated neurological examinations are not enough to activate impaired brain mechanisms which normally lead to arousal.

By its very nature, the hospital environment and the emergency procedures which it makes possible add to the deprivation caused by the patient's neurological impairments. Once the state of emergency is over, the patient is moved from the hustle and bustle of the intensive care unit to the further deprivational environment of a one-or two-bed room. Examinations become less and less frequent. Any tendency for the patient's condition to deteriorate is augmented by these further losses in environmental stimulation.

Although some patients in coma recover consciousness spontaneously, IAHP believes that, given two children of the same age with essentially the same type and degree of brain injury, of whom only one achieves arousal spontaneously, it is likely that a higher degree of stimulation inherent in the environment plays a role in that recovery. Many of the children who recovered consciousness before their first visit to IAHP did so only after they were discharged from the hospital, still in coma and with unfavorable prognosis as to ultimate arousal. In their homes they were given stimulation, provided through the love, care, and attention of family and friends, which, even though unplanned, random and unorganized, was greater than that in the relative deprivation of the hospital environment.

## PLANNED SENSORY PROGRAMS AS THERAPEUTIC INSTRUMENTS

In any comatose patient consideration should be given to the possible value of stimulation itself as a therapeutic instrument. A carefully planned and organized program of sensory inputs should be instituted at the earliest possible moment. For this purpose IAHP pioneered the concept and organization of the Coma Team as long ago as 1965. It is readily possible for the Coma Team to work around the life-support mechanisms required by the patient. Because the blindness, deafness, and insensibility to tactility of the child in coma is functional, residing in the brain and not in the eyes, ears, and tactile receptors of the skin, there exists even in the injured brain of the comatose child an unmeasurable potential for recovery of consciousness.

To accomplish this the program must be orderly and persistent, stimulation being applied with the utmost frequency, intensity, and duration. Even minor but definite gains, occurring day by day, week by week, month by month in response to such a program are indications for continued effort.

I remind you of the celebrated case of Karen Quinlan, who, after taking a combination of alcoholic beverage and tranquilizing pills is now in her fourth year of coma. At first life-support systems ensured her vegetative survival. Thirteen months after its use began, Karen could at last be "weaned" from the respirator. At the present time Karen continues to breathe independently. We believe that two factors contributed to Karen's ability to resume this vital function. The first factor was the passing of enough time for surviving nerve cells in her respiratory control center to regain sufficient functional capability to provide spontaneous control of respiration.

The second factor was the contribution to the functional recovery of the respiratory control center by the actions of the respirator, which mechanically produced in Karen's lungs, in her respiratory musculature, and in the ribs and joints of her chest the movements of inhalation for a total of over 10 million times. By way of their rich nerve supply, every structure involved in these movements sent feed-back signals to the respiratory center. In the view of the Institutes, Karen's brain benefitted from this form of what we term respiratory patterning.

This orderly, persistent, and intensive environmental input, although not intended for such a purpose, nevertheless elicited Karen's unmeasurable, residual potential for spontaneous breathing. One must ask to what degree a planned program of sensory inputs directed at seeing, hearing, feeling, tasting and smelling might have elicited similar responses in these functions and thereby have helped achieve arousal not only in Karen Quinlan but in countless other comatose young people before their overall physical condition deteriorated beyond recall.

## CONCLUSION

This, then, is the IAHP position on coma: IAHP considers that it is unreasonable to conclude arbitrarily that the unconsciousness of the young person in coma, occurring at a time in life long before degenerative processes begin to add obstacles to recovery, is such that "he cannot be aroused even by powerful or painful stimuli." Such a decision may be warranted only if that person has failed to respond to a wide range of truly strong stimulation applied with great frequency and intensity and with an uninterrupted persistence in a carefully designed program lasting at least weeks or even months. Every comatose child deserves this test of his potential for recovery.

## COMA RECOVERY

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Coma is the lowest level of consciousness or, in other words, the state of unconsciousness. It is also defined as that state from which an individual cannot be aroused, even by painful or noxious stimulation. This is a most unfortunate definition, because as a result of this inability to arouse the individual, many people have thought that as a consequence, treatment is not necessary. Therefore, we may be better off defining and determining what arousal actually is.

Arousal is a function of the reticular activating system which derives its name from a lacy network of thin fibers in the brain stem. The reticular activating system is located between the spinal cord and the diencephalon (or midbrain, phylogenetically), which is in the very heart of the central nervous system and occupies the entire core of the brain stem. It receives information from all the sensory functions of the body. These sensory functions send their information along a bundle of fibers that courses through the spinal cord and the brain stem, giving the information off to the reticular activating system at many different levels. Once the information is sifted and analyzed in the reticular activating system, the appropriate selected information is distributed to the various parts of the cortex to maintain a normal state of function and activity. In slices through the different levels of the brain stem with the appropriate coloring stains, the neurons and nerve fibers can be displayed, and the reticular activating system is noted to occupy a central location. There are some lateral components which are not important to us for this discussion. This location is maintained as one rises through the brain stem into the upper medulla, lower pons, upper pons, and into the diencephalon or midbrain.

If the reticular activating system is interrupted — by toxic substances that have been ingested, by body poisons that are inappropriately eliminated, or by injury to the head — the result is coma. However, a number of individuals have noticed that not all comatose patients succumb; some do, in fact, recover. Therefore, there has to be a grading of coma.

Classically, coma is graded as light, moderate, severe, or deep, the ultimate state being brain death. I personally do not like this type of grading, because it is vague and very subjective; others feel the same way. Recently, as a result of a national drive and national grants and encouragement on an international level, efforts have been established to create more specific or more accurate levels of coma. A group in Munich, using stimuli of fixed and known intensity and duration, has applied stimulation in the optical, acoustic, tactile and electrical domains and measured responses up to 30 sec after the onset of stimulus, achieving an eventual grade of 0 to 40. The system has a disadvantage, however, because it does require instrumentation, delicate tools, takes time, and cannot be readily performed at the bedside of any comatose individual. Therefore, a group in Glasgow, led by Teasdale and Brian Jennett, established a more realistic coma grading system, which can be performed at the patient's bedside without any sophisticated instrumentation, as a matter of fact, without any instruments at all, and can be performed very rapidly, measuring eye opening, verbal response, and best motor response; these responses are graded from 1 to 4 for the eye opening, 1 to 5 for the verbal response, and 1 to 6 for the best motor response. The resultant grade of 3 to 15 is the sum of the grade on each one of the responses.

Coma outcome is now predicted as a function of the coma grade on the Glasgow scale and those who are in a grade of 3 to 5, have a course predicted to result in death or vegetative coma.

In our own experience, when we see an individual such as a comatose 10-year-old boy in the hospital, we have agonized year after year after year, and our own statistics seem to correspond to those nationally diffused. Last year, of 13 successive patients admitted in this type of coma, 10 have died. In addition to the agony of searching for a treatment, we have had heartbreak after heartbreak telling such patients' families or parents: "Billy is going to die," and 2 days or 4 days or 10 days later coming back and telling Mrs. Jones or Mr. Jones: "Billy is dead"!

But we have long had the belief that there is regenerative power or recuperative power within the brain. This has been supported by the discovery of Sir John Eccles, that regeneration can occur; more and more articles have appeared in recent years in the literatures supporting and demonstrating this concept. In addition, we have become familiar with Doctor LeWinn's statements, and the work of the coma team, and have been very impressed by what we have seen with our own eyes at the Institutes for the Achievement of Human Potential. For the past 8 or 9 months, therefore, we have taken a very vigorous approach to the treatment of coma. We have had 16 successive patients ranging in age from 4 to 80, most under 30, with an average age of 27, 10 were males, 6 were female. They were all graded on the Glasgow scale and were in the grades 3 through 5. I would like to remind you of what we said just a few moments ago, that comas on the Glasgow scale graded 3 to 5 usually are interpreted to mean death or vegetative coma. Of our 16 patients, 10 had suffered head injuries; 4 had hypoxia or lack of oxygen, due either to smoke inhalation or to drowning, and 2 were in a coma because of brain tumors.

We had immediately initiated all the classical techniques to maintain bodily functions such as hypothermia, which cools the body down to about 90°F, in the hope of maintaining a decreased cerebral metabolism thereby reducing the oxygen requirements. When respiratory support has been required, they have been intubated and connected to a respirator, and if a dilated pupil has been present, indicating pressure within the intracranial cavity, either due to a blood clot that might require surgical evacuation or, more often, to just simply diffused swelling and bruising of the brain, then appropriate medication has been administered to try and decrease this swelling. In addition, antibiotics have always been given when infections have occurred.

On top of the classical methods of treatment, we have applied the techniques of the coma team described by Dr. LeWinn, which consist of multimodal, neurosensory stimulation. I would like to remind you about what I said concerning the reticular activating system — that it is a massive relay system for all the sensory input into the body and it uses this sensory information to achieve a state of arousal. Of significance in this technique is the need to apply the stimulation with frequency, with intensity, and with duration, and in all modes of sensory input. Therefore, every 30 min, auditory stimulation is applied, consisting of sharp or loud clapping of wooden blocks close to the patient's ear or rapid contact of two metallic objects, grinding, scratching, and voice stimulation, either by the staff or by the parents or relatives. The latter has proved to be extremely helpful from two points of view: first, the voices of relatives and parents are familiar to the comatose patient, and tend to be better perceived; second, the relatives and parents are no longer helpless onlookers developing a sense of frustration, but are actively participating in the recovery of their injured relative or child. Every hour visual and tactile stimuli are provided with repeated bright, flashing lights in the eyes for the visual aspect and for the tactile stimulation, touch over various parts of the body,

temperature stimulation by applying towels or sheets soaked in either ice cold water or hot water, painful stimulation by the application of pressure in the supraorbital ridge or behind the ear or knuckle pressure on the sternum, and pinching of sensitive areas of the skin. All the joints are stimulated by vigorous manipulation of the limbs and pressure is applied to the large muscle bulks such as the calf and the biceps. Every 8 hr, olfactory stimulation is applied by the use of strong, odorous substances such as rotten eggs or perfume, and gustatory stimulation is provided by such substances as hot mustard, hot peppers, or lemon juice placed on the tongue. This type of stimulation is carried out 24 hr a day, every day, until the patient arises from his coma. Stimulation is continued, thereafter, but with modifications to apply information to those areas that still display deficits.

Applying these techniques, 16 (100%) of our patients have recovered from coma, arousal occurring within 3 to 7 days; 75% have returned home. They have achieved a functional status in 14 to 150 days and it is at this point that they go home, not to an institute, not as vegetables. Two, who were fairly recent admissions, are still hospitalized. Two are alert but remain severely handicapped physically, and they are in long-term facilities because they have no families to take care of them. Of the 12 who have returned home, two-thirds have fully recovered with no detectable deficit whatsoever, and one-third are independent but still have some physical handicaps or behavioral malfunction from which they are in the process of recovering.

To end on a happy note, the young boy I just mentioned, admitted in coma, is now among those who are home and fully recovered.

In conclusion, I would like to mention that even though we have had 16 successive happy results and that mathematically such numbers are statistically significant, the number 16 is a very small number in medical terms. Therefore, our data must by no means be construed as definitive or conclusive; this is only a preliminary report. However, we have made the presentation to show you how we feel about coma, that we feel that regeneration is possible or that recuperation is certainly possible, that we intend to continue treating our coma patients extremely vigorously and that from now on, we are going to be adding some studies to these patients to try and determine the effectiveness of the stimulation or of the various modalities of stimulation by measuring cortical-evoked responses through the electroencephalogram and by modifying the intensity and the duration of the various stimuli to achieve maximum efficiency. It is also hoped that we will be able to develop programs of stimulation for the different levels or grades of coma.

THE CONTROL AND PREVENTION OF SEIZURES IN CHILDREN,  
A DEVELOPMENTAL AND ENVIRONMENTAL APPROACH

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We present a new concept for the control and prevention of seizures in children. The concept and the procedures which implement it are based on recognized principles of neurophysiology and development. Their clinical value and effectiveness have been demonstrated in hundreds of brain-injured children who are or have been patients of the Institutes for the Achievement of Human Potential. Because of limitations of time we shall be able to give only an abbreviated overview.

The concept embraces three factors which, in our experience are fundamental in understanding and controlling seizure mechanisms in children. They are (1) maturation and development of the brain; (2) the functional integrity of the brain, and (3) the nature of environmental influences affecting the brain.

In 1942, Temple Fay, in his classic article, "The Other Side of a Fit," (ref. 1) pointed to the fact that all human beings possess the neurological mechanism by which seizures are produced. Fay was a superb, innovative physician who at one time occupied the chairs of both neurology and neurosurgery at Temple University Medical School. A devoted student of human origins and development, subjects on which he wrote extensively, Fay saw the functions of the human brain in the light of their evolutionary progression. To acquire such insights, the fundamental contributions made by Raymond A. Dart to the understanding of the origins of human movement could not have been lost on Fay. Glenn Doman, who worked closely with Fay, listened very carefully to him, understood the significance of what he was saying, and, in the many years that have followed, derived the neurophysiological principles basic to the achievement of human potential and to this concept.

Fay described the seizure mechanism as a defensive reflex, inherited from our evolutionary forebears, the amphibia. In these creatures it originally served the specific purpose of accomplishing rapid escape into the sea from life-threatening terrestrial environmental inadequacies, especially those of oxygen and nutrition. In man, activation of this residual reflex mechanism, in our view, almost invariably by an adverse environment, causes an assortment of those bizarre behavioral patterns known as fits, seizures, epilepsy, grand mal, petit mal, and by many other terms.

As human development progresses in the brain from the early infantile functional level equivalent to that of the amphibia, the seizure mechanism becomes increasingly controlled and submerged by the cerebral cortex. This is similar to the cortical submergence of other deep-seated reflexes such as the startle and the sign called Babinski. In the immature brain, before cortical control is established, adverse internal and external environmental conditions can readily activate the seizure mechanism. As cortical control advances, it requires increasingly severe environmental adversity to release the mechanism.

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Although other cerebral structures, particularly the cerebellum and the reticular system, are integrated with the cortex in developing control, it is the cortex that plays the primary role in holding the seizure mechanism in check or releasing it. The factors of developmental maturity, functional integrity, and the environment are most effective in their actions on the cortex. For example, it is the difference in degree of cortical developmental maturity that makes children, who may seem otherwise to be well, susceptible to seizures associated with fever, whereas such occurrences are rare in adults.

With regard to cortical functional integrity, it is the loss of this factor that gives the overtly brain-injured children of the Institutes a seizure prevalence rate of 454 per 1000, which is more than 70 times greater than the best available figure of 6 per 1000 for the general population. The Institutes figure does not include children whose seizures have been purely fever-associated or which appeared as a single, isolated occurrence, although we believe that under any circumstance a seizure is a signal of a cortex in distress.

With regard to environmental effects on the cortex, I have seen seizures occur in healthy adults who have suffered uncontrolled massive, acute hemorrhage to the point of exsanguination. Here at NASA you have demonstrated the same phenomenon in ostensibly healthy adults by inertial deprivation of the brain of its blood supply through centrifugation. However, the numerous potential causes of environmental adversity capable of affecting the cortex and precipitating seizures are ordinarily much more subtle, involving nutritional, respiratory, climatological and meteorological, emotional, and other diverse influences.

In the child with seizures these three factors, developmental immaturity, brain injury, and environmental adversity, rarely occur singly. In our view, all children with seizures are at least minimally cortically brain-injured. In the child who is overtly brain-injured, developmental and maturational processes are slowed and cortical control of the seizure mechanism delayed. The inappropriately used term "mental retardation" is witness to this fact. The environmental problems of the brain-injured child are multiple and monumental, involving, in addition to those already mentioned, high susceptibility to infections with their associated fevers, disturbed fluid balance, nutritional imbalances, and numerous other adversities. Adding cortical injury to developmental immaturity greatly increases the child's seizure tendency. The additional superimposition of environmental adversities impairs even further the actions of the cortex and its integrated relationships with cerebellum and reticular system in controlling the reflex seizure mechanism. The clinical result is heightened seizure activity.

We turn now to an unfortunate aspect of the control and prevention of seizures. I refer to the use of anticonvulsant drugs which has been considered to be the treatment of choice since the introduction of the bromides in 1857 and phenobarbital in 1912. Upward of 50 different anticonvulsant drugs have come into common use. As the search for new agents continues, uneasiness about the ineffectiveness and toxicity of those which have had extensive clinical trial has been growing during the past 5 or 6 years.

The concerns of the Institutes in this connection have existed for more than a decade. More recent pharmacological research has confirmed our impression that the anticonvulsant actions of these agents are achieved by pharmacodynamic effects on the brain which are grossly unphysiological and contrary to established principles of normal human neurological development and function.

They create a barrier between the child's brain and the sensory elements in his environment on which he is dependent for developmental and maturational advance. Their depression of cortical functions not only intensifies the existing environmental deprivation which characterizes the brain-injured child but often, in going beyond the level of seizure suppression, induces loss of cortical control of the seizure mechanism and thereby actually becomes the *cause* of seizures.

In addition to their actions on the cortex, the most popularly used agents – phenobarbital, phenytoin, and diazepam – stimulate the Purkinje cells of the cerebellum constantly and relentlessly. This heightens the inhibitory effects on the seizure mechanism. However, although the factor of cellular fatigue due to this persistent drug action has not been recognized, there is no doubt that it occurs. It is probable that such neuronal fatigue is a forerunner of the widely reported degeneration and loss of Purkinje cells in the cerebellum accompanying the use of phenytoin. The ataxia and other disabilities incident to taking phenytoin have generally been confused with the effects of the brain injury underlying seizures. Although it has now been recognized that injury of the cerebellum by drugs is not infrequently responsible for these manifestations, there seems to be little realization that this same injury is also responsible for release of the seizure mechanism and, therefore, for recurrence of seizures even while the anticonvulsant drug is being taken.

Within the past 6 months, the destructive effects of phenobarbital on the very young brain have been reported.

The Institutes do not see how justification of the use of anticonvulsants is reasonably possible, especially since we have developed and employ effective, physiologically-founded methods for controlling and preventing seizures. Moreover, this approach is free from harmful effects.

This is now the procedure of the Institutes in all children who come to us taking anticonvulsants. We begin with a careful study of each child's specific needs in terms of (1) development and maturation, (2) the treatment of his underlying brain injury, and (3) the deficiencies and adversities in his environment, all of which contribute to his predilection to seizures. As procedures for filling these needs are begun, detrimental and obstructive drugs are removed slowly and gradually but progressively and totally in those children who are still taking them. The clinical effectiveness of this approach, including the results of withdrawing anticonvulsant medication was reported by Dr. Roselise Wilkinson during the early part of this week in the Philadelphia segment of the eleventh annual meeting of the World Organization for Human Potential.

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## VESTIBULAR INFLUENCES ON OTHER SENSORY AND MOTOR PROCESSES

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## INTRODUCTION

Some 40 years ago psychologist John Dashiell pointed out that the vast majority of work on sensory processes had been conducted as if each sensory system consisted of an "airtight sensory modality." This continues to be the case today in spite of the fact that all sensory modalities undergo various modifications by appropriate application of a secondary stimulus, a principle which has been noted by scholars for hundreds of years. The fact that there is an increasing awareness of this basic principle is, I think, well illustrated by the fact that 10 years ago a publication of the American Society for Testing of Materials spent a number of pages discussing sensory interaction as a factor in their work. Of course Jean Ayres' book "Sensory integration and learning disorders," emphasizes the importance of sensory interaction with some emphasis on vestibular effects. I would like to illustrate the point further by describing an old Croatian custom.

It is said of an old Croatian toast, in which they ever so gently touch the wine glasses together, that this part of the ritual is for the little ears. The eyes, they said, can admire the color; the bouquet is for the nose; the lips receive cool pressure; the tongue savors the taste. But they said, "What of the poor little ears?" So they gently clink their glasses. Now that is a nice story to emphasize the way our senses work together in such a commonplace event as drinking a glass of wine. However, for a long term member of the vestibular cult, it is an illustration of gross sensory prejudice. But then, I suppose, those Croats who developed the ritual probably were unaware of the importance of the kinesthetic and vestibular senses. The kinesthetic sense was, nevertheless, stimulated as they tapped the glasses. But what of the poor little nonacoustic ears? They may not have been stimulated by the Croats in the ritual of the toast, but their little nonacoustic ears probably received plenty of stimulation in the dancing which came along later in the evening.

It is a widely accepted principle that learning, retention, and even motivation are improved by stimulating as many of the learner's sense modalities as possible. This principle applies in a variety of learning situations. Since this meeting is at Ames Research Center, I can begin by pointing out that a great deal of effort has been expended in the past 20-25 years in examining the use of motion information in addition to visual displays in the simulation of flight for training as well as research. Studies here at Ames and elsewhere have shown that stimulation of the semicircular canals and otolith organs by rotary and linear accelerations may either help or hinder performance depending on the nature of the information and the task involved.

## OBJECTIVES

My objective in the discussion to follow is to note how the little nonacoustic ears may influence or interact with other sensory processes, but first I would like to cite three other illustrations of the way sensory processes interact.

1. *Visual inputs influence taste.* Remember the “good old days” when we all had to color our own margarine so it would not taste like lard? The coloring material did not change the gustatory stimulus, but the visual input did.

2. *Vision influences vestibular processes.* John Stewart and I have shown in our work here at Ames Research Center that sensitivity to rotary acceleration in an enclosed cabin in darkness is increased fourfold by simply supplying a visual reference inside the rotating room. William Elsner has shown that the way pilots process suprathreshold angular accelerations is also different when the visual reference is present, and Steven Dockstader has reported a similar difference for the after-effects of accelerations.

3. *Kinesthesia aids the teaching of reading.* Nearly 50 years ago, psychologist Grace Fernald developed what she called the kinesthetic method of teaching reading for retarded readers. She emphasized the movement of the arm as the student traced the large letters on a chalkboard or large sheet of paper. I always thought that the emphasis on kinesthesia was useful. But at the same time, I also felt that in practice she really used kinesthesia, touch, vision, and audition in an effective multisensory technique.

## VESTIBULAR STIMULATION AFFECTS OTHER SENSORY PROCESSES

Vestibular stimulation has widespread effects throughout the central nervous system. It is important to note that it is not motion per se that is the stimulus to the vestibular mechanism but an acceleration. Furthermore the vestibular sense organs are extremely sensitive to these accelerations. Some of the vestibular connections produce direct effects on other sensory systems while others produce indirect effects through the sensory motor systems. A major function of the vestibular system is to stabilize the position of the eyes relative to the head so that smearing of the retinal image is reduced or eliminated. This works with remarkable efficiency during self-locomotion and during slow, passive rotation in a rotating vehicle with the observer looking at a well articulated outside world. On the other hand, during passive rotation with the observer viewing objects such as an instrument panel in an enclosed vehicle such as an aircraft, the stabilizing process is inappropriate and certain reflex eye movements must be suppressed to maintain visual acuity.

## VESTIBULAR STIMULATION HAS DIRECT EFFECTS ON OTHER SENSORY PROCESSES

### Oculogyral Illusion

A number of studies over the years have demonstrated that when individuals are passively rotated in an enclosed chamber or aircraft, fixed visual objects within the cockpit viewed in darkness will appear to move in the direction of a rotary acceleration. Similarly, objects outside of the cockpit will appear to move in the same direction if they are viewed in an unstructured field. This type of apparent movement has been called the oculogyral illusion. It is of some importance as a potential hazard in night flying. An interesting aspect of this type of apparent visual motion is that it may last for many seconds and under optimal conditions as long as a minute or two.

## Oculogravic Illusion

Stimulation of the otolith organs by linear acceleration by rotating an individual on a centrifuge produces another type of apparent motion which has been called the oculogravic illusion. This effect is also observed in an enclosed compartment or in darkness. On the centrifuge, two types of motion may be observed. For example, if the observer faces in the direction of rotation he feels himself tilted outboard, and a fixed visual target before him will appear to rotate and be displaced outboard in the frontal plane, the angle of apparent rotation being very close to the change in the direction of resultant force acting on the body including the otolith organs. Similarly, if the observer faces the center of rotation on a centrifuge and views a fixed visual target directly before him, as the centrifugal force is increased, the target will appear to move and be displaced upward as he feels himself tilted backward. Again the distance in angular displacement is approximately equal to the change in direction of the resultant force. Furthermore, the oculogravic illusion is maintained at its maximum level as long as the centrifugal force is constant, at least up to 4 hr.

It is worth noting that deaf, labyrinthine defective subjects show a different temporal pattern of response for the oculogravic illusion as compared with normals, but they do perceive the oculogravic illusion. Consequently, it appears that tactual and other sensory processes are involved. The effects have been demonstrated both in the laboratory and in flight.

## Audiogyral Illusion

It has also been demonstrated that rotary acceleration affects sound localization. For example, if a person is exposed to rotary acceleration to the left in a rotating chair, short duration sounds appear to be displaced in the opposite direction. The effect decays after a brief stimulus following a pattern similar to that of other effects associated with rotary accelerations.

## VESTIBULAR STIMULATION INFLUENCES SENSORY MOTOR PROCESSES

It has been pointed out that vestibular stimulation produces eye movement, that is, nystagmus, which stabilizes the eyes with respect to the external world and maintains good visual acuity. This can be demonstrated by moving the fingers back and forth slowly before the face. At about 0.5 Hz the eyes can follow the motion and maintain clear vision, but at about 2-5 Hz the fingers blur; the visual system is ineffective at these frequencies. Now, if the fingers are held fixed and the head is moved at 2-3 Hz, clear vision is maintained. Thus it is clear that vestibular stimuli can stabilize the eyes in the head at greater frequencies of oscillation than the eyes themselves can control. However, during prolonged passive rotation with vision within a rotating cockpit, the nystagmus is inappropriate for fixed objects and stabilization does not occur. Furthermore the effects are prolonged. Thus, vestibular nystagmus may either help or hinder visual processing depending on the total stimulus conditions.

Another vestibular effect which influences visual processing has been demonstrated recently at Ames Research Center. Clark, Randle, and Stewart have called this the vestibular-ocular accommodation reflex. This phenomenon was demonstrated by observing ocular accommodation on a recording optometer following high-level, rotary acceleration of short duration. The effect produced was

an anomalous myopia which under optimal conditions was as large as 1.75 D and lasted for a minute or more. Similarly, Markham, et al. at UCLA have shown that mechanical stimulation of the utricle produces an anti-accommodation reflex in cats while de Santis and Gernandt showed that pupil size is influenced by mechanical stimulation of the utricle in both cats and monkeys.

Probably the most widespread effect of complex vestibular stimulation is a variety of vestibular and other sensory inputs leading to a complex of signs and symptoms: sweating, pallor, nausea, and vomiting, that is, motion sickness. This is clearly associated with motion of various types and an intact vestibular system. Ames Research Center has extensive ongoing research on motion sickness. This includes basic research on animals and methods to control the signs and symptoms of motion sickness. Patricia Cowings has developed a novel approach to this problem in an attempt to control the signs and symptoms of motion sickness using autogenic feedback training. This method shows promise of helping to control zero gravity sickness.

## VESTIBULAR STIMULATION AND FLIGHT SIMULATION

Ever since the beginning of flight in heavier-than-air aircraft, simulators have been used to study various flight problems. This continues to be the case at Ames Research Center, and in studying man-vehicle interactions, one of the basic questions is: Should simulators for training and research be fixed-base (stationary) or should they move? The question can also be stated another way: Should vestibular stimulation be used in flight simulators? John Stewart and I with a number of university students have been looking at the effects of rotary acceleration on certain flight related tasks: (1) tracking tasks and (2) monitoring tasks.

### Tracking Tasks

We have given airline pilots selected visual tracking tasks with cursors to align with a fixed target. The equipment behaves somewhat like a flight director in the cockpit of an aircraft and follows a quasi-random motion pattern. The pilot's task is to keep the cursor superimposed on the target using a hand controller. This task is performed with and without concurrent whole body motion in the simulator, that is, with and without vestibular stimulation. The results show that airline pilots do perform somewhat better with congruent vestibular stimulation than without, but there are marked individual differences. Furthermore, spurious vestibular stimulation, that is, rotary acceleration that is not task related, causes poorer performance, but the pilots can learn to compensate for it. Thus in general, vestibular information which is congruent with the visual display helps in tracking tasks.

### Monitoring Tasks

The effects of a simple accessory stimulus on a single response to a primary stimulus have been studied for many years. Most of the work has been conducted on the interaction of visual and auditory stimuli. The results show that the effect of the accessory stimulus may be either facilitative or inhibitory. A limited number of studies have also been carried out with visual motion on a cathode-ray tube as the primary stimulus to which the subjects respond with concurrent rotary acceleration

as the accessory stimulus. The primary findings of these studies show a temporary inhibition of response (TIR) during concomitant stimulation by rotary acceleration; that is, response time tends to be longer when visual ( $\underline{a}_L$ ) and rotary ( $\underline{a}_R$ ) acceleration are presented together although the rotary motion is not necessary for the subject to make the correct response. It has been shown that (1) TIR increases with the relative magnitude of  $\underline{a}_R$  to  $\underline{a}_L$ ; (2) during prolonged  $\underline{a}_R$  the response time to  $\underline{a}_L$  increases for some 30 sec and then declines following the same pattern as the subjective magnitude estimates of velocity during constant  $\underline{a}_R$ ; (3) the TIR occurs for both central and peripheral vision; (4) the TIR increases during concurrent tracking; and (5) the TIR does not occur with small cursors.

## SUMMARY

The various studies reported show quite clearly that vestibular influences on other perceptual and sensory motor processes are widespread. John Stewart and I have called this gyrovisual modulation for the case of vestibular-visual interactions. This modulation may take three forms: (1) gyrovisual inhibition, for example, monitoring tasks with TIR and spurious motion; (2) gyrovisual facilitation, for example, tracking; and (3) gyrovisual conflict, for example, motion sickness and disorientation in flight.

Each of these has its own special mechanisms and unique outcomes. Some of these interactions have been worked out but whether vestibular inputs help a particular perceptual or motor task can only be determined by experimental trial. Contrary to the belief of some, there seems to be no simple, general facilitory or inhibitory effects of vestibular stimulation. Thus, although vestibular influences are widespread, they are complex and dependent on the total stimulus situation.

## VISION

Richard F. Haines

Ames Research Center

Thank you very much, Ralph. It is a genuine pleasure to be here, indeed. I am honored to be on a panel such as this because the topic under discussion is a vitally important one. I would like to get right into the subject of human vision because I know you are waiting for lunch. Those who study the subject of how we see, that is human visual perception, realize very quickly that they have entered into a land of mystery, a place where complex neurophysiological processes seem to be almost overwhelming in their resistance to understanding, a place where the biochemical processes underlying vision at all levels of the nervous system are ever-changing over time. Several previous speakers have already mentioned this plasticity, this maturation effect. But these and a myriad of other difficulties should not deter us from delving as deeply as possible into the subject.

My own research here at Ames Research Center over the past 14 yr, has encompassed many aspects of vision, with special emphasis upon the influence of stressors of various kinds — high acceleration, high ambient brightness in the environment, high temperature and humidity, prolonged bed-rest (to simulate weightlessness), and so forth. But I am purposely not going to talk about these subjects today because there is not enough time to present any single topic in sufficient depth; I would much rather try to give you some food for thought. While my comments will be confined primarily to human vision, I hope you will permit me to digress into several tangential areas.

The major thesis I would like to leave with you today is that therapy for autistic and brain-damaged patients should rely far more on visual input than it has to date. I would like to cover four rather diverse subjects in this regard which will not, perhaps, appear to fit together right away. A secondary thesis is that visual input should be employed to provide controlled stress. So let me begin. I am going to use figures; I'm going to go fast — so just sit back and relax and enjoy them. The first subject I'm going to discuss is our ability to perceive color.

All that we know by our sense of sight arrives either by waves or bundles of photons from the tiny portion of the total electromagnetic energy spectrum known as the visual spectrum. This spectrum is defined primarily by the wavelength filtering effect of the water molecule which is present in most of the transparent media of the eye, which figure 1 shows. Here you see that the visual spectrum is largely a function of the transmission of the cornea, and to a lesser extent the other transparent media of the eye. Imagine what it would be like if we could see into the ultraviolet and the infrared portions of the energy spectrum. Some individuals can perceive "near" ultraviolet wavelengths because they do not have lenses. They claim to be able to see vague patches of blue in the heavens at night emanating from certain ultraviolet radiating stars. I would like to suggest that the physiological limitation of being able to see only this limited range of wavelengths forms a potential barrier to man's intellectual understanding of space and forms that now lie hidden from us.

How would you like to exist within a visual environment that remained homogeneously gray? What would you be able to learn from such an environment? Certainly not very much. Would you prefer an environment like that shown in figure 2? You see what the sense of color adds? In the

following series of illustrations I would like you to ask yourselves the question “What can I learn from each scene?” I am not dealing with its aesthetic characteristics, however. (Note: Due to space limitations numerous slides presented at the meeting are represented by only one figure in this paper.) I hope by now you would prefer the high information content of the outdoor nature slides to the totally gray environment. One of the points to be made is that although we are surrounded by natural, highly colorful surroundings which we often times disregard, seldom do we use them in therapy. What if you were continually surrounded by the visual environment shown in this slide which shows a rigid, homogeneous high contrast pattern? Would your nervous system eventually suppress the dark squares or perhaps the white areas, or both?

A variation on this same theme is illustrated in the next slide by a more random yet almost as rigid a colored environment. It is a basement power generating room in a hospital, where the architect has been rather innovative in painting the pipes. But how would you like to live there? What role does a fixed, immobile visual environment play in the recovery of a patient, who may not be able to visually avoid the flat ceiling over his bed and the walls (except by closing his eyes)? In the next illustration try to find effective depth cues. This is an artificially produced psychedelic slide. What is it about this rather ambiguous source of visual information that makes it worth looking at at all? Almost nothing is already known about this figure, whereas what you bring with you to interpret the previous illustration is a tremendous amount of prior experience from earlier exposure unless of course you have been born blind. Where do you look in this slide and why? How long do you look there? Where do your eyes focus? These are all very relevant questions, I think, to the topic of this symposium. These are the kinds of fundamental questions which those of us interested in the development of human potential should raise. Perhaps some new therapeutic breakthroughs might be made if we took a few steps backward out of the usual confines of our traditional scientific disciplines of optics, physiology, biomedicine, chemistry, neurophysiology, etc. Perhaps we should close our minds deliberately to the usual questions for awhile and ask seemingly new and unrelated questions. For instance, some of Carl Jung’s conceptualizations regarding the collective unconscious and its many intriguing symbols comes to mind. If it is valid to think of the unconscious as containing “prototype” symbols, from which at least some of the content of our conscious mentations arise, then would not it make sense to see if we can discover what keys, that is, what therapeutic techniques might be found which would unlock these complex symbols now buried in our unconscious? Is clinical counseling and its therapeutic techniques the only way to tap these symbols? Earlier Dr. LeWinn defined coma as a state of unconsciousness from which it is almost impossible to raise the patient. My suggestion purposely takes us down into the unconscious; this is why I bring this issue up.

Let me go back to the matter of color, though. Some of us are color-dominant people. Unfortunately, we do not know what that means precisely, but it’s still a handy concept. I would like each of you to look at the next slide and judge whether the right-hand or the left-hand object is most like the center one. (Note: This slide showed a red triangle on the right, a red square in the middle and a red green square on the left.) How many selected the right-hand object? How many selected the left-hand object? About half and half. How many did not select either one? Thank you. Each of us carries around within us certain acceptance criteria, for example like the one you just used to make this judgment. We use these unconscious criteria — perhaps color dominance might be one — to help us decide how best to respond to the demands of the world around us. Now I am not an expert in the field of how to develop human potential as many of you are, but it seems to me that one approach in helping to develop increased human potential might be through a purposeful

application of controlled stress. The little exercise of having to judge the colored shapes just now is an example of a very mild form of “controlled stress.” Scientific research by Hans Selye and others has shown that either having too much stress or too little stress is potentially harmful. So, finding just the right amount and kind of stress, for a given person in a given environmental situation, is an important part of the challenge that we face. In the few remaining minutes I have today, I am going to comment on the possible role that visual input can play as a central component of this stress. Let me move on to my second subject then, which has to do with the limits of our visual field.

In figure 3 we see a diagram of the normal visual field limits for monocular and binocular vision. The point is that binocular vision occurs within the dashed contours labeled “right” and “left eye limit.” Most of our visual field mediates binocular vision, that is, it provides us with stereopsis cues. Just as a radio antenna possesses a well-defined, fixed limit to its radiating beam, so the human visual system possesses a fixed limit in the angular extent to which the visual world may be received. Now a point that I would like to make here is that many bedridden patients are unable to move their heads or their eyes, yet their eyes remain open hour after hour, day after day. And thus they are relatively locked into their visual environment. A second point is that perhaps man’s limit of vision may provide the brain (perhaps the cerebellum) with an unconscious coordinate reference system. I would not be surprised if the retinal region that subserves the far visual periphery, that is, near the limit of the visual field, actually helps us maintain overall equilibrium. Perhaps the far periphery acts as an optical lever arm. Many of us wear glasses yet we have long since forgotten about the supporting frames. Because we say to ourselves unconsciously (and intellectually) that their function is only to support the glass lenses – that is enough. Long ago we learned to repress the eye glass frame image on the retina. Yes, we have probably forgotten altogether the reason for having these frames in the first place. And yet our brain has not. I maintain that the unconscious level, our brain stores these frame-related coordinates and uses them for stability reference purposes. Our peripheral visual capabilities often are disregarded, but let the combat soldier or the hunter of big game in the bush notice movement at the extreme limit of the visual field and he will quickly take appropriate action. This brings up the important matter of training.

Soldiers and hunters, to mention but two occupations, are trained to maximize the information coming from the limit of the visual field, whereas, most of us are not so trained. I think we have been disregarding the visual periphery. Indeed, I want to leave this subject and its implications with you as a challenge. Perhaps we have been underestimating the visual periphery. All we receive visually from the side enters the pupil, the opening into the eye, through a very narrow slit aperture, which is shown in figure 4. I took these photographs years ago to measure how much light enters the eye at extreme peripheral angles. Perhaps we need to think more about using peripherally located sources of information in guiding purposeful behavior, of aiding patients toward recovery when they lack adequate vestibular equilibrium, of developing new ways to transmit visual information to the brain when the foveal region is no longer functioning as it should. In short, there are hitherto unexplored ways of taking more advantage of this part of the visual field.

The third subject I would like to discuss, very briefly, today is the often disregarded role of Earth’s gravity. Imagine what it would be like to live on a planet whose center of gravity was not at the center, but located somewhere near the surface of the planet. Trees would grow at oblique angles to the surface, you would build a building at a slant, because this is the way it would be gravitationally stable, you see. It would be something like living in a town like Pisa, Italy, everything built would be parallel but at an angle to the Earth’s surface. The usually expressed belief is that our perceptions of what constitutes the vertical and horizontal in an environment such as that, soon would

allow for living adequately. In other words, we would probably adapt very quickly, and I think that the research by Dr. Brant Clark, John Steward and co-workers will show this to be true. We have a dynamic, highly plastic nervous system, which is effectively adaptive to what I would consider to be a stress. At first it would be a stress. While you may think this is a moot issue or that we should not spend any time thinking about it, because we don't live on such a planet, I think we should. I think such conceptualizations force us to take a new look at what we have merely accepted without question before. Another related question is what would our depth perception be like in an environment where everything were seen normal, that is, 90° to the line of sight, as many patients, again, have to deal with? I took the photograph shown in the next slide from the air, about 6000 ft up, over western Iowa farmland. The receding lines, even at this steep viewing angle, tell us something about where we are with respect to the ground. The surface detail on the ground also tells us something about its identity. But what about hospital patients who lie prone for long periods of their lives and who stare at the ceiling and walls that are almost always flat planes? Does the range of visual accommodation, that is, the focus response of their eyes, somehow adapt to somewhere around the distance limit imposed by their visual field? This is a point I have tried to make many times before — that we need windows in hospital recovery rooms, windows to the outdoors, to optical infinity, to changing light, patterns and color. Windows are valuable visual escape routes. In drab, homogeneous environments is there a tendency to destabilize the visual fixation mechanism, so that the brain does not receive a normal retinal image pattern? By the way, I am not necessarily advocating the use of super-graphics on the ceiling.

Now, in figure 5, I would just like you to read what it says. Is everybody done? Read it again, please, just to make sure. (In the same figure, during the presentation, a slide was shown that included the word “the” in the bottom line in red.) It is as St. Paul said in his letter to the Corinthians, “For now we see through a glass dimly.” We may not perceive all that we might. Perhaps a technique like this might be used in a new test for color perception. I believe that there are many people who will not see, for various reasons, the second “the” in this figure until it is emphasized in some appropriate way. Perhaps some of those of you here who are red-green blind still might not understand what has happened here. Your neighbor can tell you.

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Now, in contrast to being presented more than we might perceive, the opposite is also true. Figure 6 simply shows the fact that the absence of a physical stimulus, in this case the missing bridge up ahead, can lead to very vigorous activity on the part of the engineer — at least the passengers hope so.

Finally, the fourth and last subject I want to discuss is that of visual perception. Visual perception involves a process of progressive and continual integration of sensory information and I am going to allude to these processes in the next series of figures. As I go through this series I would like each of you to deal emotionally with your uncertainty. At what point in the series of figures do you begin to feel comfortable? Let us say that your life depended on identifying correctly the true identity of the figure. That is perhaps extreme, but at least assume that some traumatic thing might happen — you would get an electric shock, for instance, if you did not identify it correctly. You would be anxious now. This is a starting point (fig. 7). The point I want to illustrate is that perception, the process of integrating all this sensory information you have been hearing about, is progressive — it involves maturation, it involves developing a frame of reference as quickly as possible to put bounds or limits of familiarity (memory functions) to what you see. How about now? Anything better? No! How about now (fig. 8)? Anybody like to venture a guess? How about now (fig. 9)?

A face? That is a good guess. It is a face? A plant? This sounds like a Rorschach technique, doesn't it? What? Flowers? Well, let us wait and see. Now what is it (fig. 10)? A rug pattern. Your anxiety level should still be high (fig. 11). It is getting lower for anybody? Are you struggling emotionally (fig. 11)? Do not just sit there: struggle (fig. 11). We are getting close now. A field of flowers. That is a good guess. A vegetable, a garden, a painting, . . . good for you. All right. There we are (fig. 12). Very nice. See how long it took. You see the role of the periphery of this picture? If each of you had to fixate at the center, for instance, and your eye muscles were paralyzed, could you come this far in this simple exercise or would you go on further? It is a painting, obviously, and one that I love. Yes, it is a painting by Seurat. Now, can you find the original dot? That's the final question. I think we are at the point now where fundamental and creative research is needed.

Creative research is needed that is aimed at crossing the frontier which stretches between us and completely unknown territory. One cannot at the same time know and not know. The illusion that we can comes from the application of an erroneous philosophy, an unscientific approach, and perhaps intuition in such a field as human development which many in science regard as still uncharted. It seems valid to view the area of the development of human potential as an enclave of scientific ignorance which is surrounded on all sides by well-charted territory. This is the case, for example, in biological research, which is aimed at filling the gap separating our knowledge of living beings and cells from our knowledge of biochemistry and of the physics of the molecule, of which that living matter is made. It is reasonable to suppose that this gap will be filled in the fairly near future and we can only hope that our own gaps of understanding of how the human being can achieve full and ultimate potential, will likewise be filled in the near future, through a creative application of man's intellect, his intuition, and an inner awareness of his largely untapped spiritual nature.

I hope I have made the point today that what we need in the field of development of human potential, are new ways of looking at old problems and indeed this may sound trite, yet it may be one of the most difficult things of all to achieve. Personally I think that the rewards of achieving this are going to be very great, both for your patients, and for yourselves, because you will have a better understanding of yourselves, of your own limitations, of your own capabilities. It has been a genuine pleasure to be here since I have looked forward for some time to this opportunity to address so many gifted and dedicated people. I would like to leave each of you with a challenge. It is simply this, that each of you take a whole step back from what you are doing in order to take a new look at it. See if you can devise new breakthrough approaches to the kind of therapy you are working with. I wish you all the best in your work and thank you very much.

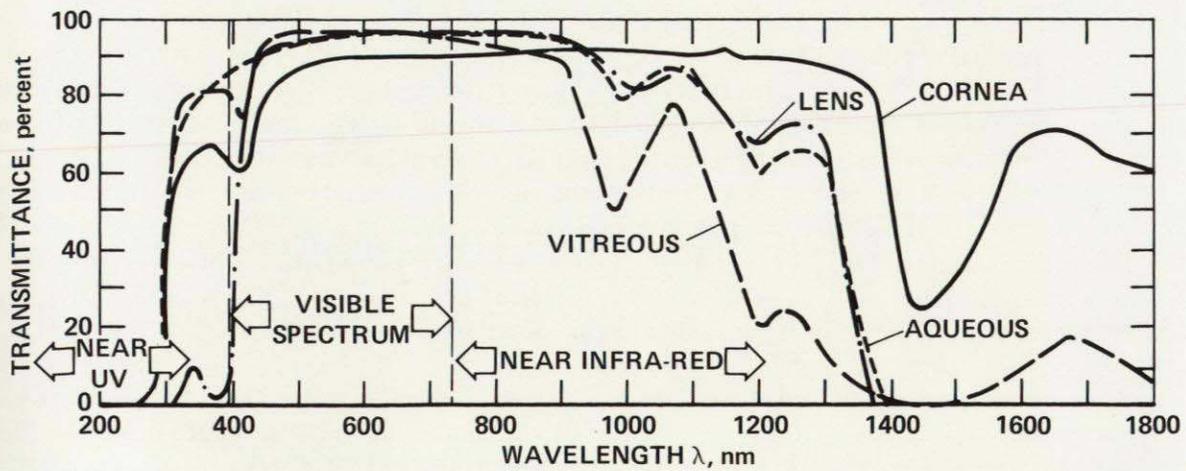


Figure 1.— Spectral transmission characteristics of the human eye.



Figure 2.— Aerial photograph of a sunset to illustrate possible quantitative and qualitative information sources present.

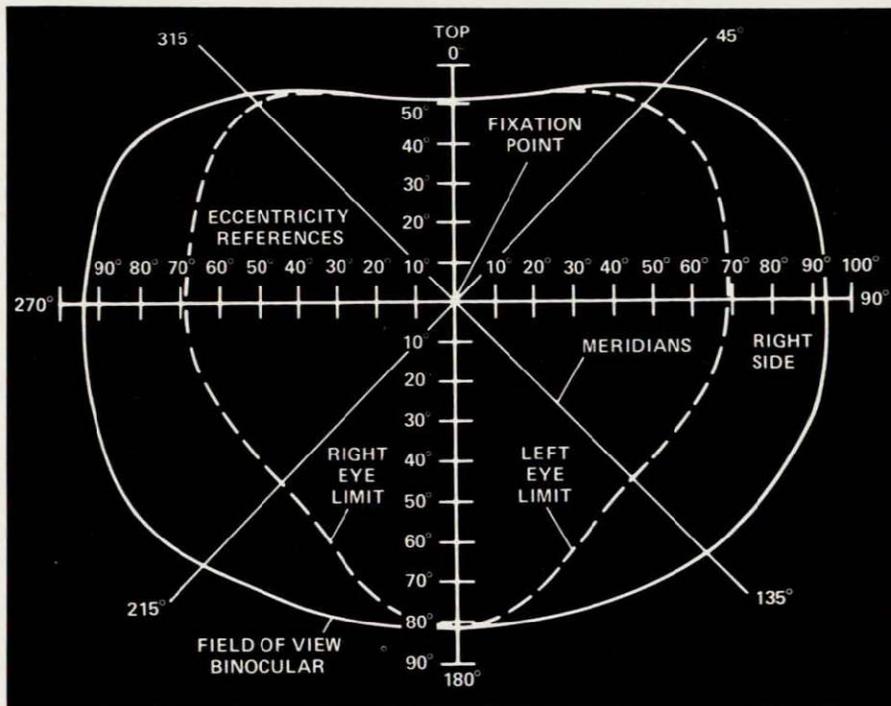


Figure 3.— Diagram of the binocular and monocular human visual field limits.

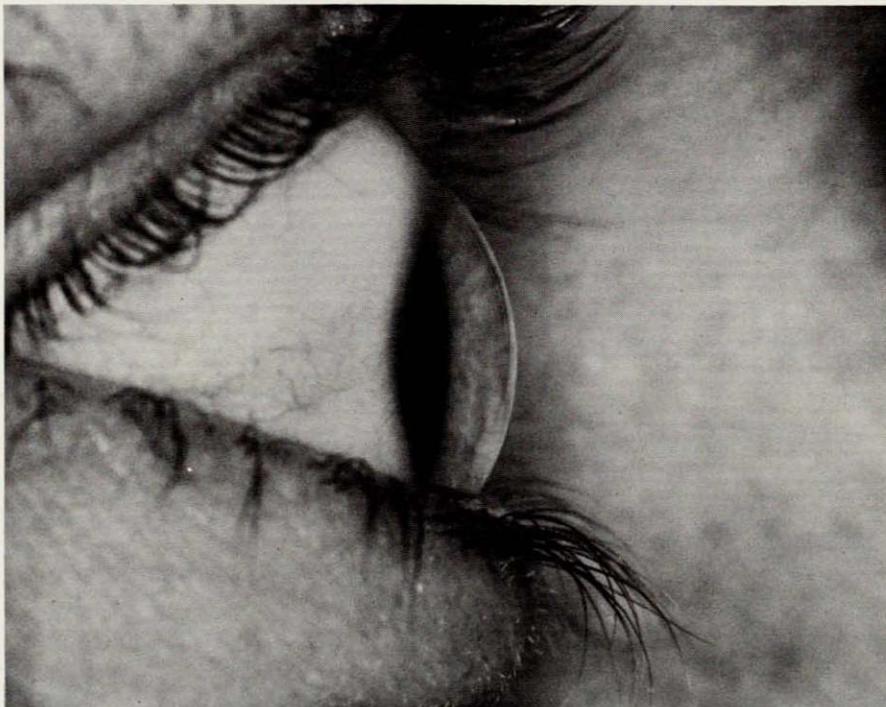


Figure 4.— The human pupil as seen from the side.

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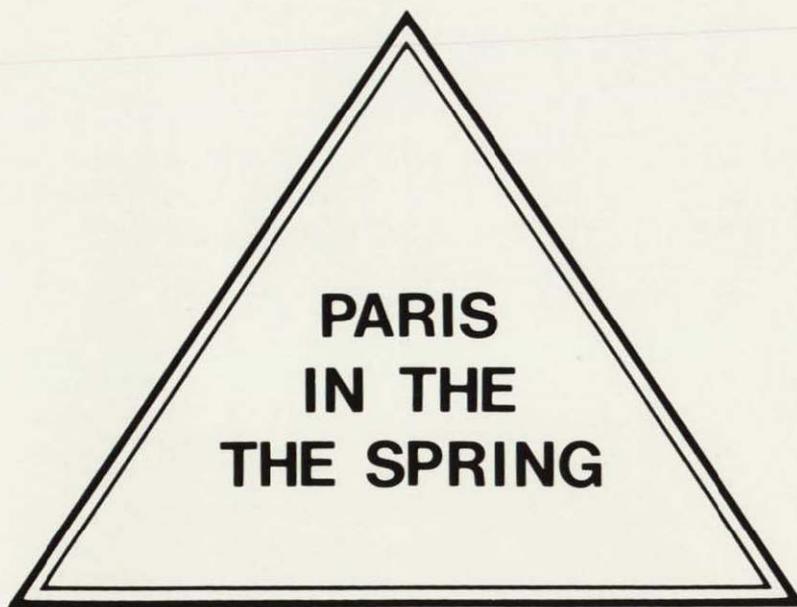


Figure 5.— Illustration showing that we may not perceive everything contained in simple stimuli.

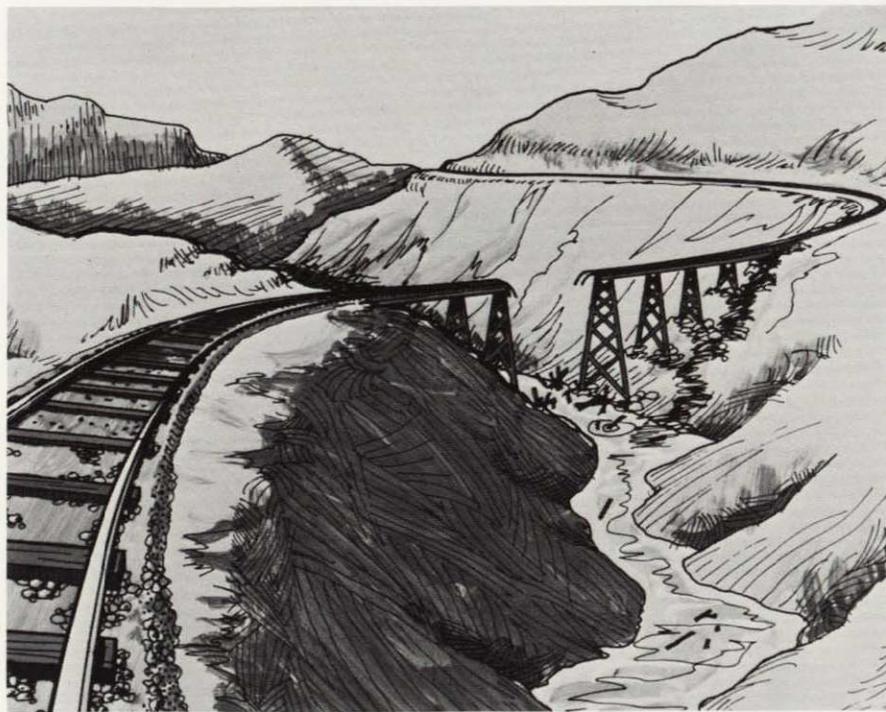


Figure 6.— Illustration showing that the absence of a stimulus (the missing portion of the bridge ahead) can lead to vigorous activity on the part of the engineer).



Figure 7.— The first in a series of illustrations of progressive integration of visual information into a meaningful context.

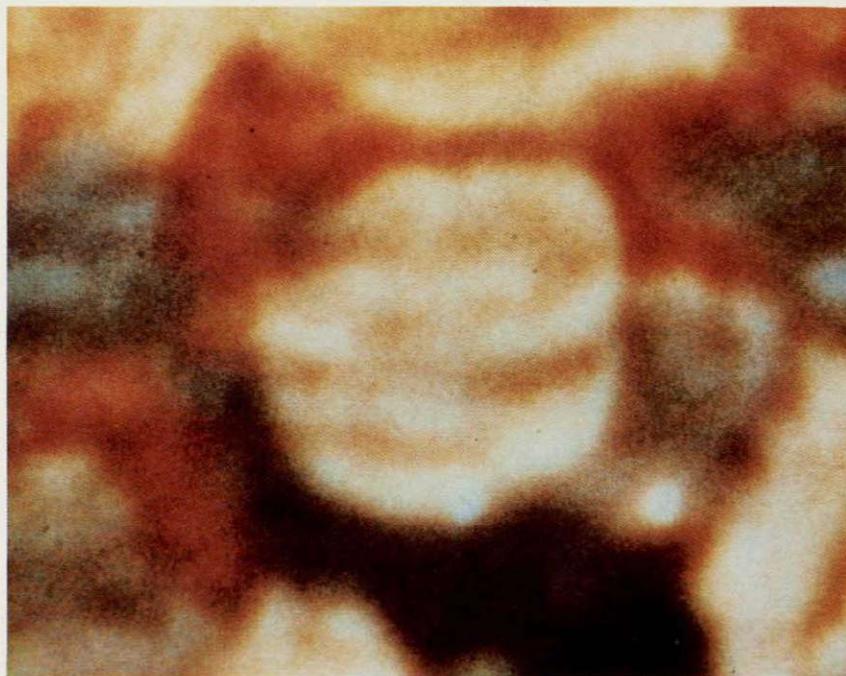


Figure 8.— The second in a series of illustrations of progressive integration of visual information into a meaningful context.

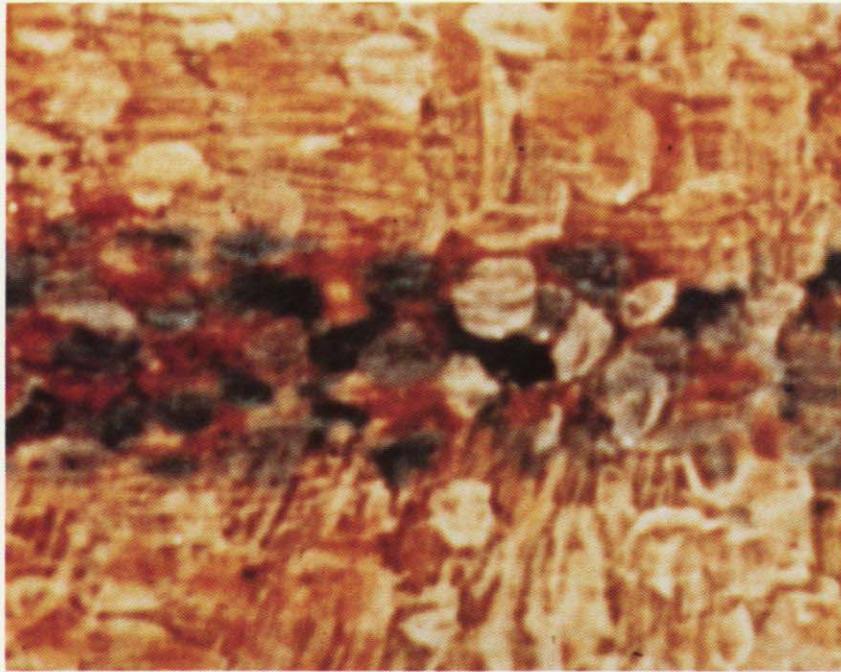


Figure 9.— The third in a series of illustrations of progressive integration of visual information into a meaningful context.

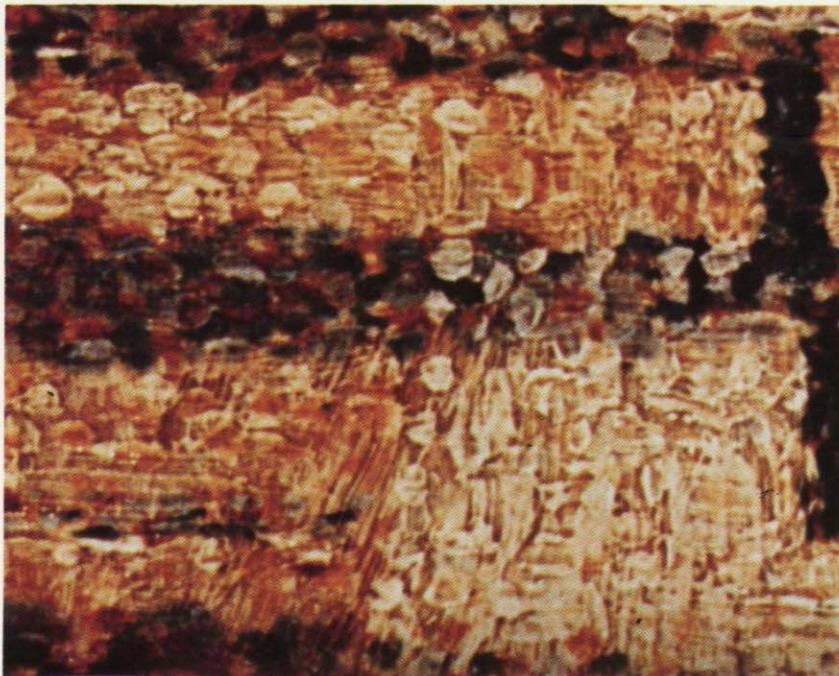


Figure 10.— The fourth in a series of illustrations of progressive integration of visual information into a meaningful context.

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Figure 11.— The fifth in a series of illustrations of progressive integration of visual information into a meaningful context.

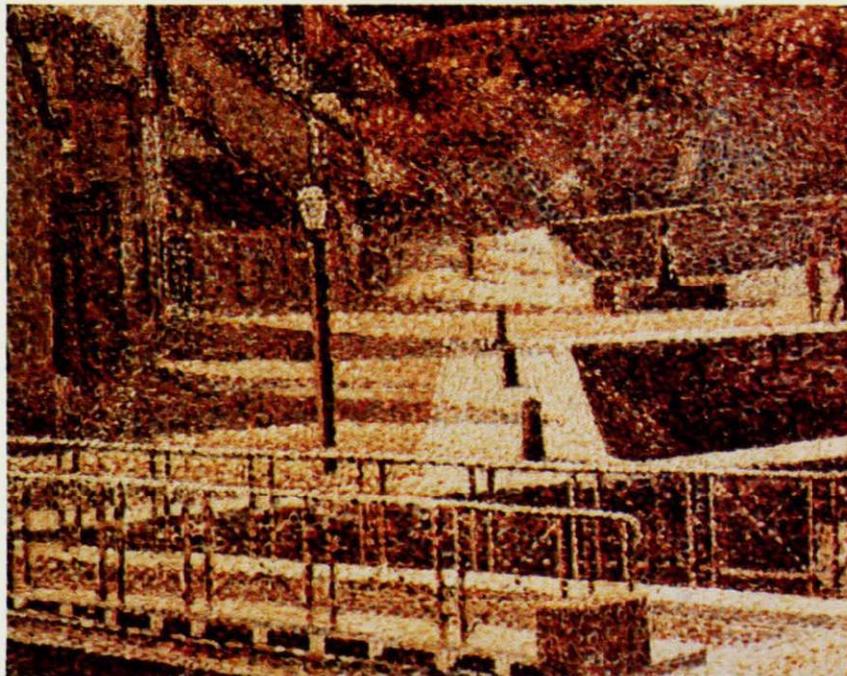


Figure 12.— At last the delightful painting by the well-known artist Seurat appears as a result of the final perceptual integration of numerous subelements.

life, could have important additional effects when taken in quantities a thousand times that needed to prevent death by the corresponding deficiency disease astonished me. This idea seemed to me to be something new in physiology and medicine. I was astonished enough to start reading the literature, and I found that there were reports about many other substances affecting the functioning of the brain when they were taken in larger than usual amounts. For example, Milner had shown by a double-blind study that a gram of ascorbic acid per day given to schizophrenic patients led to a statistically significant greater improvement than the placebo that was given to similar schizophrenic patients. Glutamic acid taken in amount 10 gr per day was reported by several investigators to have a significant effect on the intellectual ability of borderline mental retardates, and many other substances were shown to affect the functioning of the brain.

These facts seemed to me to be so important that I invented a word — orthomolecular — meaning having the right molecules in the right amounts. In 1967-1968 I published two papers, one entitled “Orthomolecular Somatic and Psychiatric Medicine” and the other “Orthomolecular Psychiatry,” in which general arguments about the dependence of chemical equilibria and rates of reaction on the concentrations of the reacting substances were advanced as the explanation of the value of large doses of nutrients and other substances normally present in the human body. Now we have an orthomolecular medical association and a journal of orthomolecular psychiatry, and there are orthomolecular institutes in several cities in the United States.

The brain is probably the most sensitive of all organs to change in its molecular composition. There are no doubt a great many molecules that must be kept in about the right concentration in order that the brain function well, and we have developed mechanisms to this end. In both guinea pigs and human beings these homeostatic mechanisms function so well that the intake of vitamin C can be varied a thousandfold with only a twofold change in the concentration of vitamin C (ascorbate ion) in the brain cells. Only in the last stages of scurvy, after prolonged deprivation of vitamin C, does the concentration of ascorbate in the brain fall sharply. The twofold range of concentration may not seem to be important, but in fact it probably is important, for really effective mental function, to have the concentration of the ascorbate at the high end of this range, corresponding to a high intake of the vitamin, rather than at the low end.

I could give many examples of orthomolecular medicine, but I shall restrict myself to a few. There is a disease called tardive dyskinesia, which is caused by the drugs that are given to young people, especially, to control mental illness. Tardive dyskinesia is a very distressing disease, because the young people find that the involuntary movements, especially the repeated extrusion of the tongue, make it difficult for them to go out in public. It was reported just a few months ago that an intake of 10 gr of choline per day controls tardive dyskinesia in many patients. Choline, although not a vitamin, is important to the brain. Acetylcholine was the first of the neural transmitters to be discovered. The usual intake of choline in food is about a gram per day, and the human body can also synthesize choline, so that the dosage of 10 gr per day is not an excessive amount. This increased intake may lead to increased synthesis of acetylcholine or in some other way influence the action of acetylcholine. Studies ought to be made now of the possible value of a high intake of choline for other neurological diseases.

Also, C. R. Burch, a well-known physicist who invented the Burch microscope, has discovered by experimenting on himself that his epileptiform seizures can be controlled completely by an intake of 2 gr of inositol per day. Inositol is an orthomolecular substance, present in some foods,

and it is understandable, as with choline, that changing its concentration might be effective in controlling neurological diseases.

At about the same time that I was working the field of orthomolecular psychiatry I became interested in vitamin C in relation to the common cold. Irwin Stone, a biochemist who was then living on Staten Island (he now lives in Mountain View, California) wrote to me, a dozen years ago, sending me copies of four papers that he had published in 1965 and 1966 about "hyposcorbemia, a molecular disease." He gave some arguments to the effect that the natural intake of vitamin C is perhaps 100 times as great as the usually recommended intake. He suggested that I would be protected against the common cold if I were to take 3 gr of vitamin C per day. My wife and I tried this regime. It was clear that it did protect us against the common cold. In 1969 I was asked to speak at the opening ceremonies of a new medical school in New York – Mt. Sinai – and in my talk there I mentioned that by taking large doses of vitamin C you could prevent the common cold. a physician on the staff wrote a strong letter to me about encouraging the vitamin quacks, on whom the people of the United States waste \$600 million a year, and asked if I could point out any double-blind study that had shown vitamin C to have any greater value than a placebo. I had not checked the literature about the common cold before 1969, but I began looking in the literature, and found that four double-blind studies had been made, each of which showed that vitamin C had more value than a placebo. When I pointed this out to the physician in New York, he refused to accept the evidence. I was so impressed by this display of bias and by the misrepresentation of the facts in the medical textbooks and the reference books, that I wrote a book about vitamin C and the common cold, published toward the end of 1970. This book *Vitamin C and the Common Cold*, was followed in 1976 by a larger one *Vitamin C, the Common Cold, and the Flu*. In the meantime, Irwin Stone had published in 1972 his book, *The Healing Factor: Vitamin C Against Disease*.

During the years from 1970 on I was in correspondence with members of the Food and Nutrition Board of the National Research Council–National Academy of Sciences, U.S.A., which every 5 years puts out a report on nutrition with recommendations about the daily intake of various nutrients, including vitamin C. In earlier years this Board had recommended 75 mg per day, and in 1960 they were recommending 60 mg per day for an adult. In its publication, the Board states that the amounts recommended are enough to prevent for most people the corresponding deficiency diseases, and also states that vitamin C in large doses has no value in protecting against the common cold or any other disease. I pointed out that epidemiological studies have indicated that there is a considerable improvement in health and decrease in the age-specific mortality accompanying the ingestion of even an additional 100 mg of vitamin C per day. In 1974, just when I thought that I might be making some progress with the Board, the Board responded by issuing new recommendations, dropping the recommended intake of vitamin C from 60 mg to 45 mg per day. I have no explanation for this action.

There are many reasons for believing that the human body requires, for optimum functioning, about 10,000 mg per day. One argument is based on the fact that most animals manufacture vitamin C. The amount manufactured by an animal is proportional to its body weight. A 70-kg goat manufactures 13,000 mg per day, and in addition gets a considerable amount in its food. Other animals manufacture between about 4 gr and 20 gr per day, calculated to a 70-kg body, with an average of about 10 g per day. This is the main reason why I myself take 10 gr per day – I do not believe that the animals would manufacture ascorbate in this amount if it were not important for their health that they do so.

Irwin Stone in his book has discussed the many published reports about the control of viral diseases and bacterial diseases by large doses of vitamin C. Probably the most important study in this field is that carried out by Dr. Morishige of Fukuoka Torikai Hospital, Fukuoka, Japan, in collaboration with Professor A. Murata of the Agricultural-College-in-Saga, Japan. Dr. Morishige had made a study of vitamin C in relation to wound healing while he was in medical school. When he was working in another hospital in Fukuoka he tried giving various amounts of vitamin C to surgical patients who were receiving transfusions of whole blood. He observed what seemed to be a protective effect against serum hepatitis, and when, in 1967, he became the Chief Surgeon of another hospital, Fukuoka Torikai Hospital, he carried out some systematic studies with some surgical patients who received transfusions of whole blood; some received little or no ascorbate and others received large amounts. The incidence of serum hepatitis in the patients who received little or no vitamin C was 7 percent, whereas there was no incidence among the patients, in a series of 1380 who received blood transfusions after surgery, who had been given 22 per day or more of vitamin C.

A striking example of the value of vitamin C in preventing and treating disease is provided by the work of Dr. Ewan Cameron, Chief Surgeon in Vale of Leven Hospital, Loch Lomondside, Scotland. Dr. Cameron developed the idea that a considerable control of cancer might be achieved by stimulating the body's natural protective mechanisms. In 1966 he published a book on this subject, *Hyaluronidase and Cancer*, in which he emphasized the possibility of strengthening the intercellular cement in the normal tissues around a malignant tumor by inhibiting the enzyme hyaluronidase that is liberated by the malignant cells, and that attacks the hyaluronic acid of the intercellular cement that binds the tissues together. Then in 1971 Rotman suggested to Cameron that vitamin C might be involved in the production of an inhibitor of hyaluronidase. I gave a lecture in which I said that Cameron's goal might be achieved by the ingestion of large amounts of vitamin C, in that the intercellular cement is strengthened by fibrils of collagen, and we know that vitamin C is required for the synthesis of these collagen fibrils. Cameron read an account of my lecture that was published in the *New York Times*, and wrote asking how much ascorbate to give to the patients. In November 1971 he began cautiously administering 10 gr of vitamin C per day to a patient with terminal cancer. The patient responded well, and during the next few months Cameron tried the same treatment with other patients. He now has given ascorbate as the only therapy to more than 500 patients with advanced cancer, and to a smaller number with cancer at earlier stages. The results are very promising. In a comparison of 100 patients with advanced cancer who received 10 gr of vitamin C per day and 1000 matched controls, the same age, the same sex, and with the same kind of cancer (10 controls per patient) who were treated in the same way, by the same physicians, and in the same hospital except that they did not receive ascorbate, the ascorbate-treated patients have lived, on the average, 300 days longer than the controls. Fifty times the fraction have lived more than a year after being pronounced terminal — 22 of 100 ascorbate-treated patients and 4 of 1000 controls. In 1974 Morishige in Japan began the same treatment, and his observations on the first 55 patients with advanced cancer to be treated with ascorbate are essentially the same as those reported by Cameron.

The use of ascorbate and other nutrients in controlling cancer needs to be thoroughly investigated. We do not yet know what the best dosage of ascorbate is for cancer patients, nor do we know about possible effectiveness of other vitamins, such as vitamin A. In our Institute we have been studying nutrition in relation to skin cancer in mice, caused by ultraviolet light. We find that there is a significant decrease in the number of malignant tumors developed by the mice when they are transferred from ordinary mouse food to a diet of raw fruits and vegetables. The increase is far

greater, however, when 2.5 percent of sodium ascorbate is added to the diet of raw fruits or vegetables (or to the regular mouse food). The mice on the best diet have only 17 percent as many malignant tumors as those on ordinary mouse food, and we think that it might well be possible to protect them completely against skin cancer caused by ultraviolet light by finding the optimum diet.

I believe that by improving nutrition, especially by increasing the intake of vitamin C, and by other health practices, it will be possible for people to remain in good health for 25 years longer than at the present time. I think also that it is likely that people who suffer from handicaps of one sort or another can show great improvement in their condition by following the appropriate nutritional regimes, and that in this way the amount of suffering in the world can be decreased significantly.

## INTELLIGENCE

Glenn Doman,\* Janet Doman,\*\* Susan Aisen,\*\*  
 Miki Nakayachi,\*\* Gail Engebretson,\*\*  
 Conceicao de Sousa,\*\* and Bruce Hagy†

For 35 years the staff of The Institutes has observed, studied, and dealt with children ranging in age from newborn to 21 years of age. This study has taken us to every continent, with the exception of Antarctica — where I don't believe there are any children, and to 135 nations.

For the first 15 years of this study we believed ourselves to be studying one subject when in truth we were learning a different thing.

The question seemed clear enough in the beginning. Since we had proposed to look for means to make brain-injured children who were paralyzed, speechless, blind, deaf, severely mentally retarded — or all of the foregoing things — able to function in a totally normal way, it behooved us to begin with the question of just what is a totally normal child.

Nobody really knew the answer to that question.

Since children in different places are very different from each other, how much of what a child is, is pure child and how much of a child is due to being black, white, yellow, red, brown, rich, or poor? How much is due to being born in New York City, Paris, London, Rio, Moscow, Berlin, Tokyo, Bangkok, city, mountain, desert, jungle, plain, island, or wherever?

That search has taken us from the most civilized centers of the world to the most primitive places, where man is not yet even in sight of the Stone Age.

Since, as has been said, the child is father to the man, the search soon led to the question of, what is man himself?

That search has taken us to Konrad Lorenz, Desmond Morris, Robert Ardrey, Linus Pauling and a host of other geniuses.

It has taken us back 2 million years to Australopithecus in South Africa in the person of his discoverer, Dr. Raymond Dart, and forward to a mingling of today with tomorrow in the form of Dr. Ralph Pelligra and the staff of Ames Research Center.

By 1958 we began to understand that what we were actually studying was that portion of human potential, that *major* portion of human potential, perhaps even the totality of human potential which we call intelligence.

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\*The Institutes for the Achievement of Human Potential

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Although the world has found little agreement on how to measure it, (and perhaps less on what it is) we recognize without effort the high degree of intelligence in our friends and low degree of intelligence in our antagonists.

The most ancient and basic disagreement has been between the advocates of nature and those of nurture. Is it genetics or is it environment?

We have noted that both sides seem to feel that these two possibilities are, of necessity, mutually exclusive, and that both sides often use the same evidence to prove their own point.

I am a case in point. My mother is heavy, my father was heavy, so I am fat.

“Living proof of genetics,” says the geneticist.

“They taught him to eat too much,” says the environmentalist.

Here I find myself in the camp of the environmentalists since I have noted that when, for extended periods of time, I eat too little I become thin, and when, as is generally the case, I eat too much, I become fat.

What, after all these years, are our own notions, biases, observations, conclusions and in fact, beliefs? Without attempting to explain the processes by which we came to these conclusions in these few minutes we shall state our conclusions.

Almost every point is contrary to the beliefs espoused by those who accept conventional wisdom.

1. That intelligence is a function of the central nervous system and is therefore neurophysiological in nature.

2. That all well children are neurologically alike at birth and that by 1 year of age they have become different from each other. By 2, 3, 4, and 5 years of age they have become increasingly different. By 6 years of age they have become who they are and this will remain essentially fixed throughout life.

3. The world has looked at brain growth and development as if they were predestined and unchangeable *facts*; instead brain growth and development are a dynamic and ever-changing *process*.

4. This is a process which can be stopped, (as it is by profound brain-injury). This is a process which can be slowed (which it is by moderate brain-injury). But most significantly this is a process which can be speeded (as it is in geniuses, by sensory and motor stimulation).

5. We have speeded this process in many thousands of children, both brain-injured and well by supplying visual, auditory, and tactile information to the brain with increased frequency, intensity, and duration and by supplying unlimited opportunity for mobility, language, and manual competence, in recognition of the orderly way in which the human brain grows and develops.

6. Heredity and environment are springboards, not prison cells. If they were straitjackets we would all have remained single-celled creatures existing in a primordial ooze.

7. Our individual genetic *potential* is not that of our parents or grandparents.

8. Our individual genetic *potential* is that of Homo sapiens.

9. We are primarily members of the human race and only incidentally Lees, Nakayachis, Kleins, Collodels, or de Sousas, from whom we acquire such superficialities as size, color, hair, body conformation, etc.

10. Our individual genetic *potential* is that of Einstein, Leonardo, Michelangelo, Russell, Mozart, Edison, and Shakespeare.

11. High intelligence is a product of the environment.

12. Low intelligence is a product of the environment.

13. All intelligence is a product of our Homo sapiens' genetic endowment plus environment.

14. The wildly wide intellectual and physical differences in us are a result of the wildly wide differences in the specific environments in which we were raised.

15. It is the environment of poverty, not the genetics of poverty which beget poverty.

16. It is the environment of knowledge which begets knowledge.

17. There are no genetics of poverty or of knowledge. If there were how could we explain the single individual who escapes poverty or comes to knowledge?

18. Tiny children have a rage to learn because in human beings learning is a survival skill.

19. Learning begins no later than birth.

20. Function determines structure.

21. The brain grows by use.

22. First there is a need and then there is a facility.

23. Intelligence is a result of thinking.

24. Man is intelligent because he uses his brain.

25. The ability to take in raw facts is an inverse function of age.

26. You can teach a baby anything you can present in a factual and honest way.

27. It is easier to teach a 1-year old to read than it is to teach a 7-year old.
28. It is easier to teach a 1-year old a foreign language than it is to teach a 7-year old.
29. It is easier to teach a 1-year-old mathematics than it is to teach a 7-year old.
30. It is easier to teach a 1-year old any set of facts than it is to teach a 7-year old.
31. Facts are the base on which intelligence is built – without facts there can be no intelligence.
32. Children learn facts such as words, numbers, musical notes, presidents, birds, trees, reptiles, nations, flags, etc. at a rate which staggers the adult imagination.
33. If you teach a tiny child the *facts* such as words, numbers, or notes he will *discover* the laws such as grammar, arithmetic, and music.
34. Science is defined as “*A branch of knowledge dealing with a body of facts systematically arranged to show the operation of laws.*”
35. Tiny children use the same method of solving problems as do scientists.
36. Tiny children ask the same questions as do scientists.
37. The first 6 years of life are the genesis of genius.
38. Geniuses are made not born.
39. There are five steps in human intelligence, each dependent on the successful completion of the previous step.
- The first requirement for intelligence is the ability to take in fact.
- The second requirement for intelligence is the ability to store facts.
- The third requirement for intelligence is the ability to retrieve stored facts as useful knowledge.
- The fourth requirement for intelligence is the ability to combine and permutate facts and knowledge to discover new facts and laws.
- The fifth requirement for intelligence is the ability to use facts, knowledge, and laws to successfully solve problems of increasing importance.
40. The passage of visual, auditory, tactile, gustatory, and olfactory facts over those pathways actually grows the pathway itself and without respect to the content of the message itself.
41. If facts (bits of intelligence) are precise, discrete, unambiguous, new and related, that information multiplies on an algebraic curve.

42. To multiply intelligence in a tiny child we need only supply such precise, discrete, unambiguous, new and clearly related facts using the following procedure.

The first step in multiplying a baby's intelligence is to feed the baby with a huge number of clear facts and in related sets.

The second step in multiplying the baby's intelligence is to present the facts frequently to insure their permanent storage.

The third step in multiplying a baby's intelligence is to provide frequent opportunity to retrieve the facts for useful purposes.

The fourth step in multiplying the baby's intelligence is to provide the tiny child with sets of related facts so that the baby can combine and permute the facts in the greatest number of useful ways.

The fifth step in multiplying the tiny child's intelligence is to present him with ever increasing opportunity to solve problems of increasing importance.

43. We are persuaded that the foregoing points are so because we do these things daily and have been doing so for many years.

From all of the foregoing it is clear that we are pragmatic people who are essentially explorers and clinicians and as such are clearly disqualified as scientists in the present day sense of research.

We are perhaps childlike in the sense that for 35 years we have daily been faced with a huge array of facts from which we have deduced such laws as have been listed.

While, over the years, we have been fascinated by a great number of theories including some of our own, we have found ourselves much more impressed by the facts with which we have been faced daily.

Not the least impressive of the facts are the children of the Evan Thomas Institute.

These children range in age from 18 months to 5 years.

We have with us 10 children and their mothers. These children have been selected not on the basis of special ability but instead on an economic basis. We chose all the mothers from the Evan Thomas Institute who had two children on the program so that we could pay for three tickets instead of four on the aircraft from Philadelphia.

The children will read English, Japanese, do instant math, do intricate problem solving, will play music they have composed, speak in several languages, and perform olympic gymnastic routines on the balance beam and overhead ladder.

It is with a great deal of pleasure that I present the staff of the Evan Thomas Institute, the mothers, and a group of tiny budding geniuses to this group which contains so many already mature geniuses.

*The children then demonstrated their ability.*

Glenn Doman, Director of the Institutes for the Achievement of Human Potential

Janet Doman, Director of The Evan Thomas Institute

Susan Aisen, Vice Director of The Evan Thomas Institute

Miki Nakayachi, Associate Director of The Evan Thomas Institute, Director of the Language Program

Gail Engebretson, Associate Director of The Evan Thomas Institute, Director of the Music Program

Conceicao de Sousa, a Senior Staff Member of the Evan Thomas Institute

Bruce Hagy, Vice Director of The Institute for Human Development

Mothers and children of The Evan Thomas Institute

Mothers	Children and Age	
Mrs. Carrancedo	Beatrice	4 years
	Enrique	3 years
Mrs. Hord	Jesse	4 years
	Lindley	3 years
Mrs. Katz	Sean	4 years
	Brandi	3 years
Mrs. Koenig	Maryellen	5 years
	George	3 years
Mrs. Sherman	Micah	4 years
	Jason	15 months
Mrs. Dimancescu	Marc	4 years

## DEVELOPMENTAL OPPORTUNITIES IN THE SPACE ENVIRONMENT

Richard D. Norton

Trans World Airlines

The history of the human in space covers a period of less than 20 years. During that time two major and essential accomplishments directly relative to man were made. First, he simply learned to survive in the hostility of an unexplored environment, and second he developed the ability to perform useful tasks and become productive in space. The results of these achievements were beautifully demonstrated during the latter portion of the Apollo program when our astronauts not only survived a rigorous trip, but also accomplished a large variety of useful work.

This period produced a great deal of useful data on the human physiological changes which occur in space, and procedures to minimize or cope with those changes. One of the major concerns was not only how an Earth-adapted individual would react to zero g conditions, but also how that person would respond when returned to the gravity of Earth. It was the change of environment which posed the greatest questions. When the time comes that man no longer has to return to Earth, major changes in physiology may not only be acceptable, but might establish a new space-normal human.

Centrifuge experiments with animals during the past two decades have also returned a wealth of information on the effects of acceleration on growth, skeletal and muscular structures, metabolism, and longevity. While little similar data is available on the effects of chronic acceleration on humans, it is reasonable to extrapolate from some of this animal data.

I would like now to combine these bodies of knowledge with that from the human developmentalists to suggest the next use of space we might make for our own direct benefit. In other words, how can we begin to exploit space to improve human neurological function?

Aside from the unique view space provides us, other conditions exist which are difficult to create in any significant amounts on or near the surface of the Earth. Most notable of these are vacuum and a freedom from gravity. The vacuum demands that we provide our own atmosphere, as well as complete control over lighting and heating; therefore, we can provide and control these in the most advantageous amounts or combinations desired. Just as the spacecraft hardware requires specific conditions in order to maximize function and longevity, so too the human organism.

Not only must we provide the human with the most ideal environmental conditions possible, but the potential also exists to vary them in order to exert stress on the autonomic nervous system. Thus, automatic body functions could achieve maximum flexibility for purposes of life support and health. Flexibility and adaptability are keys to maximizing neurological function. For example, assuming we could isolate the human from the more temperamental spacecraft mechanical and electronic equipment, rather than maintain a constant 68°F we could radically alter the ambient temperature up and down for short periods of time to exercise and thereby improve the efficiency of the body's temperature control system. Or we could briefly increase the partial pressure of carbon dioxide in the atmosphere to stimulate the chemoreceptors of the medulla, making them more

responsive and at the same time strengthening the respiratory system by stressing and varying the demands on it.

However, it is the freedom from gravity which appears to be the most significant condition in space relative to maximizing human development. Homo sapiens is the most successful and highly evolved animal on Earth, in large part because of his ability to defy gravity. The development of hand-eye coordination and balance which allowed us to become bipedal has given us superiority in mobility and expanded our visual, auditory, and tactile horizons. Most important, it has freed our upper limbs from a role of support and balance to allow functions such as carrying, tool use, and the development of a written language.

Yet, gravity remains a dominating and controlling factor in our lives. Each of us begins life helplessly pinned to the Earth by the force of gravity. Gradually we develop counterforces against it. We become erect and mobile in a condensed replication of our evolutionary past. If gravity were removed (or nearly so) during infancy, the initial movement of limbs, torso, and head could be more rapidly developed. Early locomotion and the ability to become erect would be easier if the effective weight of the body was reduced. After such movements had been mastered, the reintroduction of gravity would pose less of a handicap.

The achievement of earlier movement would also permit more rapid development of such sensory feedback systems as the semicircular canals and the mechanoreceptors which relay information on body position, essential toward balance and coordination. Earlier movement and mobility also allow greater exposure to the environment, promoting better development of sensory functions and faster learning. Gravity is necessary to establish orientation toward the vertical and to develop the vestibular system, but early experiments indicate that as little as 0.05 g may be sufficient for this.

Beginning next year, NASA's Space Shuttle will permit much greater accessibility to the zero-gravity environment of Earth orbit. Later, the European Space Agency's space lab will be combined with the Shuttle to provide a zero-g workshop. There some valuable research could be done toward maximizing movements of an infant. Obviously the emotional and technical barriers toward sending an infant into space are presently great. In addition, the high-g launch and recovery might prove to be stressful for a physically undeveloped infant. One alternative might be to substitute an older child who is more structurally mature, but undeveloped in motor skills due to a neurological injury, who could therefore probably withstand the rigors of such a trip. Gravity is even more limiting to the movements of this type of child who must pass through the same developmental steps as the normal infant in order to gain mobility. Failure to accomplish this is common unless a major amount of assistance is provided.

Pre-space research could be conducted with infants using such devices as the helmet recently developed at Ames Research Center which allows a completely helpless individual to be totally submerged in water. This device offers a minimum of restrictions to movement or encumbrance to the user, permitting the buoyancy of water to provide relief from gravity. It allows freedom to experiment with movement without requiring control of breathing. Initial testing of this helmet has found it very comfortable to adult users. Terry, an 8-year-old child immobilized due to brain injury, reacted initially with fright due to her first experience with sudden freedom from gravity and from all bonds and contact with the Earth. She rapidly acclimatized to those freedoms and began enjoying the device, with some limited attempts at limb movement.

The exhilaration of being in this kind of environment serves itself as a motivating factor for movement. For example, you might recall experiences you have had with underwater scuba diving, or the delight shown by the astronauts moving both at zero g and in the one-sixth-g conditions on the Moon. Experimentation in aircraft flying parabolic arcs can also provide brief periods at zero g, although requiring high-g entry and exits from the maneuver. Just as this was used for the early exploration of functional problems at zero g, so it could now begin opening the use of weightlessness to promote function.

I would like to turn now to the environment of more than 1 g. Much of the animal and human research in this area has dealt with rather high levels of acceleration or long periods of exposure, and with the resulting complications. It appears that relatively low values of between 1 and 3 g are where benefits may be found.

Survival under acceleration requires exertion and work due to added stress. Movement also provides greater stimulation to the body position-sensing and gravity-sensing organs; hence the potential for improved development in these areas. It is also possible to generate reactionary movement against the forces of acceleration. Our experiments with an immobile brain-injured child in conditions of from 1.25 to 2.5 g caused at times an increase in activity level up to 100 percent above 1-g values. Periods of muscle use in arms and legs was one-third greater during centrifugation than before or after. Respiratory and cardiovascular conditioning from this work was evidenced by a reduction in average heart rate during acceleration from 170 to 125 over the course of one 3-week series of runs while physical movement showed an uptrend. It should be noted that the periods of acceleration were less than 40 min each, and that both the acceleration and the changes in g level proved significant to the generation of movement.

Animal experiments with chronic mild acceleration have demonstrated improvements in several physiological conditions such as greater blood perfusion in muscle tissue, increased metabolic efficiency or oxygen uptake, and cardiovascular conditioning. Some of the derogatory effects, such as an inhibition of growth, have been reversed to some extent after return to 1 g. Thus, placing a child in a 1.5-g environment during portions of his early years could result in the superior development of some anatomical and physiological areas. It is interesting to consider how such a child, who learns normal movement at 1.5 g, might function when returned to the less restricting gravity of Earth. The indications are that he would be superior in several areas of function and structure when compared with his 1-g peers.

In the not too distant future, structures will be built in space in which humans will exist for longer periods of time. Later, this will expand to larger space stations with a more permanent residency. In these structures centrifugal force due to rotation will substitute for gravity in order to make conditions more Earth-like for the inhabitants, and to avoid the problems associated with chronic weightlessness. Since acceleration or gravity would be zero at the axis of rotation and would increase as the distance from the axis increased, for the first time a laboratory will exist offering the full spectrum of gravity conditions. For the first time we will be able to vary gravity as greatly and frequently as we wish. For the first time we will be able to choose to locate ourselves at any gravity level along the radius we desire. We will be able to explore and utilize the area between zero and 1 g which has generally been unavailable to us.

Given those potential conditions and considering the past research and present knowledge which I have touched on, I would like to propose a scenario for human life in conditions of

controlled manipulation of gravity. Our objectives will be to maximize the development of function and structure, in turn providing the potential for greater intelligence, productivity, and social abilities. We will also attempt to reduce mortality and promote longevity.

Since life begins in the buoyancy of the womb, much of the trauma of birth could be removed by having it occur at a very low g. If our obstetrics ward was located at 0.1 g we could keep the participants and their tools in place, control fluids, and most critically reduce stress on the neonate. Rather than be immobilized by his introduction, he could continue his prenatal type movements without the confinements of the womb. Our nursery would also be located at low g and the infant given considerable periods of time at zero g to promote further dexterity and flexibility of movements.

Beginning with brief periods, the young child would be exposed to conditions of greater g to introduce the stresses caused by acceleration in a controlled manner; enough stress to cause the desired development and reactions without over-stressing. The important stimulation provided by gravity would then begin its work to develop the anti-gravity (or extensor) muscles, increase bone calcium and red blood cell count, develop the vestibular system, strengthen the cardiovascular system, and so on.

We would gradually increase the average daily g so that by age 6 it might reach 1.5, but the child would not spend his entire time at one level. Variety of g conditions will be as important as the average g level to maximize development and adaptation, and to avoid the anatomical and physiological problems associated with chronic high-g or zero-g environments. For example, we might have a zero-g gymnasium for tumbling and other dexterity activities, a 2-g playground for strength and conditioning, a 1.5-g classroom, and a 0.5-g bedroom for minimum stress during sleep. Throughout the growth years we would maintain a high-g average with greater and greater variety (fig. 1).

To conclude, I would like to go beyond the developmental period of life to complete this sketch of the human in conditions of controlled variations in gravity. Adult life in these space structures would be in conditions of gradually decreasing average daily g. Many productive functions would be more easily carried out at something less than 1 g. For exercise, a short workout or even a walk at 1.5 or 2 g would suffice, and it would be easier to dance the night away in a 0.25-g discotheque.

One need only visualize the outward appearance and inward condition of a very elderly person to see the damaging results which gradually occur because of gravity. A weakening skeleton becomes deformed from supporting the weight of the body. Tissues and organs sag and collapse downward on themselves. A weakening cardiovascular system must still provide and contain the pressure necessary to elevate blood to the brain. The aging human is literally crushed back to the Earth by gravity.

In our scenario some of these aging problems would be reduced by the superior structure we had created earlier. If this late portion of life were conducted at a very low g, the physical collapse might be greatly delayed. The elderly could remain more mobile, comfortable, and productive. Infirmary could be reduced and the potential would exist for a marked increase in the span of human life.

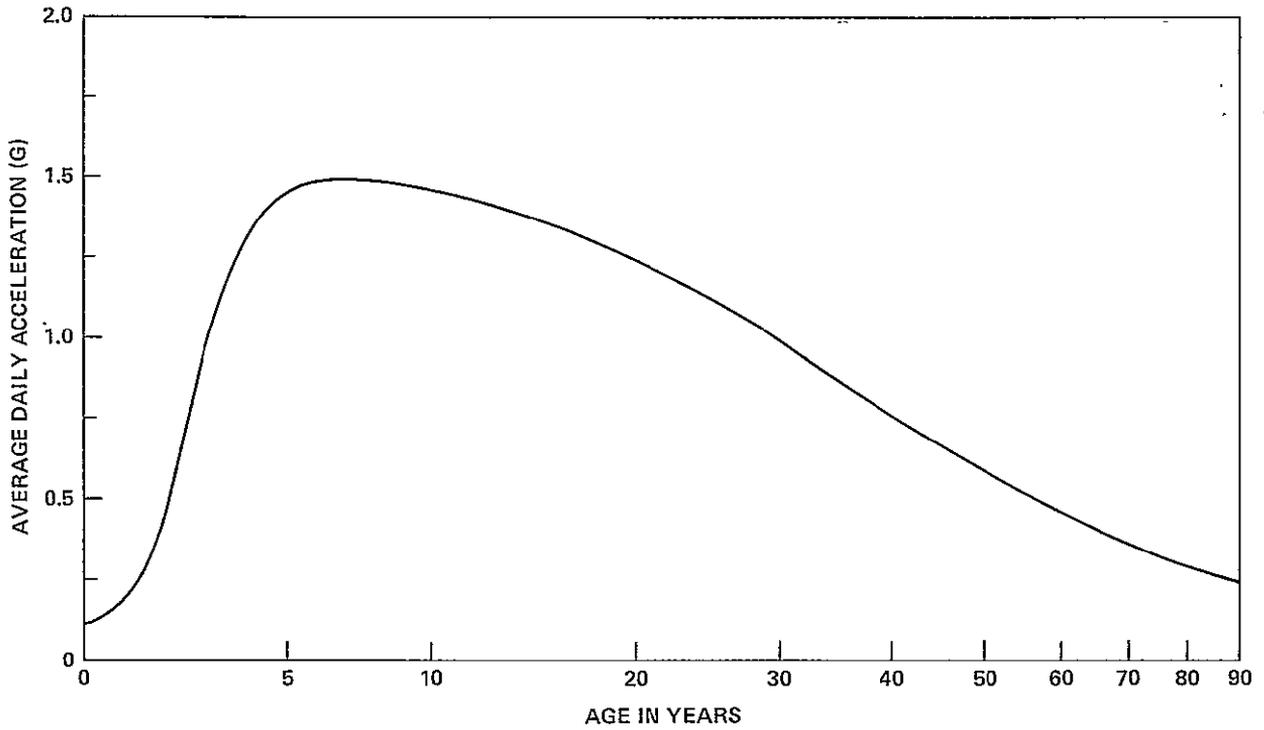


Figure 1.— Ideal gravity conditions for maximizing development and function should climb rapidly after infancy, peak during childhood, and then gradually decline with age.

1 Report No NASA CP-2063	2 Government Accession No.	3. Recipient's Catalog No		
4 Title and Subtitle Human Neurological Development – Past, Present and Future. Proceedings of a Joint Symposium, May 18, 1978		5 Report Date	6 Performing Organization Code	
		8 Performing Organization Report No. A-7630	10 Work Unit No	
7 Author(s) Ralph Pelligra – editor	9 Performing Organization Name and Address Ames Research Center, NASA Moffett Field, Calif. 94035, and The Institutes for the Achievement of Human Potential		11. Contract or Grant No	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration, Washington, D.C., and The Institutes for the Achievement of Human Potential, Philadelphia, PA.			13 Type of Report and Period Covered Conference Publication	
			14 Sponsoring Agency Code	
15 Supplementary Notes				
16 Abstract  Neurological development is viewed from the perspective of the emergence of humans from the instinct-dominated animal world to our future role as interplanetary travelers. Vision, vestibular function, intelligence, and nutrition are discussed as well as newer concepts of the treatment of perturbations of neurological function, coma, and convulsive seizures.				
17 Key Words (Suggested by Author(s)) Neurological development Coma Seizures		18. Distribution Statement Unlimited  STAR Category – 99		
19 Security Classif. (of this report) Unclassified	20 Security Classif (of this page) Unclassified	21 No of Pages 69	22. Price* \$4.50	