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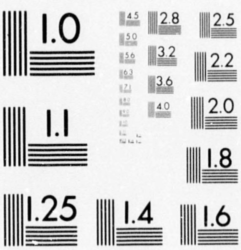

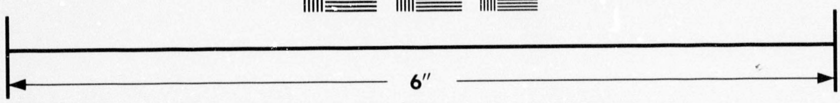

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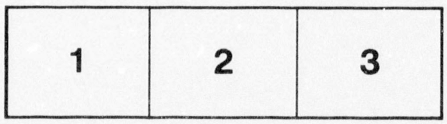

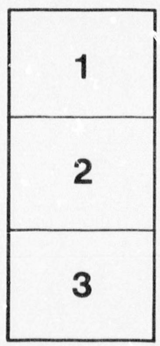

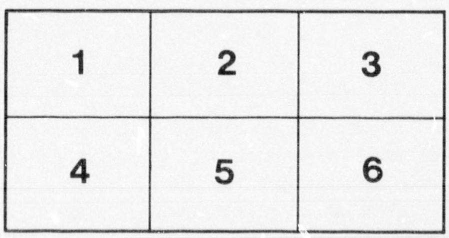

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From Fundamental to Accessory in the Development of the Nervous System and of Movements.

A DISSERTATION

SUBMITTED TO THE FACULTY OF CLARK UNIVERSITY IN FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY.

Approved: G. STANLEY HALL.

BY

FREDERIC BURK

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FROM FUNDAMENTAL TO ACCESSORY IN THE DEVELOPMENT OF THE NERVOUS SYSTEM AND OF MOVEMENTS.

By Frederic Burk, Fellow in Clark University.

Two tendencies in educational method have ever struggled in greater or less opposition—one based upon the logical divisions of the subject studied; the other based upon some theory of internal order of development in the mentality of the pupil. Theoretic pedagogy has made the latter tendency its contention. Commenius, Rousseau, Froebel and others have gained the title of "reformer" essentially because they attempted to break away from a form of education determined by the logical order of subject-matter and sought to substitute for it some theory of the psychological development of the pupil as the regulative principle. It is not until the question is brought under close scrutiny of experience or of theory, that the possibility of an essential difference between the logical order of subject-matter and the pedagogical order of mental development presents itself in any convincing way.

To illustrate: in learning to read, the logical order naturally shows us that sentences are made up of words, words of syllables, and syllables of letters; it would seem that letters being the ultimate logical simples would also be the ultimate pedagogical simples and the point of beginning for the learner. Such, indeed, was the method employed in schools universally until very recent times, and it still is widely used in some countries. But experience has shown conclusively, nevertheless, that in this matter at least, the avenue of least resistance is not upon the lines of logical cleavage, but on the contrary, it has been found that children learn to read far more readily by beginning with words or even sentences. Thus, in this case, the pedagogical order is almost the reverse of the logical order. In certain other forms of instruction, experience has as definitely established a conflict between the pedagogical development of pupil and logical order of subject which makes it doubtful that the latter is as serviceable for educational purposes as practice has often assumed.

The educational reformers — some by theoretic deductions and others by experience or by happy intuition—have attempted to bring into clearer light a subjective order in the development of mentality. Froebel, Herbart and many others certainly have made many valuable contributions which have stood tests of experience. But we have as yet no general basis in positive science for such an order; and it would seem natural that the modern biological sciences—particularly neurology and experimental psychology—should make contributions to this problem. For the purpose of bringing together in convenient form such scattered facts in these sciences as bear directly or indirectly upon the problem, this study has been undertaken. The first chapter will review the contributions in the field of recent studies of the nervous system; the second chapter will trace the development of the human hand and attempt to correlate this development with that of the nervous system. A third will review studies upon the growth of hand motility during the school ages.

Suggestions from the Development of the Nervous System.

It was but natural, in the early attempts to find a relation between the various structures of the nervous system and the different degrees of mentality observable in masses of individuals, that attention should have first been turned upon the grosser forms of brain anatomy—the shape and protuberances of the skull, arrangement of the convolutions, the size and weight of the brain, etc. Each of these features has been subjected to scrutinizing comparative study. Practically nothing, however, of psychological significance has thus far been obtained from any of these studies, except to render it more doubtful that any significant relation exists between these gross differences which naked eye or scales may detect, and the differences of mentality in individuals. Large differences in weight, for example, are shown to depend chiefly upon variations in the amount of non-nervous material—the supporting tissues, blood vessels, fluids, and the fatty protecting sheaths encasing nerve fibres. Recent investigation has been gravitating toward a solution in the finer microscopical structures of nervous tissue. While as yet the interpretation of facts in this field is more or less doubtful, nevertheless certain features are suggestive to psychology and education.

Growth of the Brain in Weight. For the sake of completeness it may be well to mention in passing the result of recent inquiries into the periods of brain growth as determined by weight. Vierordt from records of 415 males and 424 females, ranging to 25 years of age, finds that maturity in weight is practically complete at about the eighth or ninth year. The period of most rapid increase after birth, according to this investigation is from birth to four years of age. Mies[1] places the average weight of brains of new born males at 340 grammes and of females at 330. At maturity he calculates the average as 1,400 grammes for males and 1,050 grammes for females. The period of most rapid growth is that of the first nine months of life, during which one-third of the whole increase after birth is added. The second third of the whole increase is added between the ninth month and the twenty-seventh month. The remaining third is slowly obtained. Mies says maturity of weight is reached sometime between twenty and thirty years. Pfister,[2] in a study of 156 brains from birth to the fourteenth year, confirms in a general way the rate of growth as found by Mies, and his figures would indicate that the maximum weight is practically reached in the pubertal years.

While the data, from incompleteness and questionable accuracy, will not allow us to determine with absolute precision when growth matures, we may nevertheless safely conclude that the rate, rapid in embryonic life and infancy, steadily decreases; and that, in all probability, no large increment of weight is added after the ninth or tenth years.

Growth in the Cell Body and its Processes. The process of division by which new cells are created ceases in the embryonic period, as commonly stated, by the fifth month of fœtal life. Reflection upon this fact has left a fatalistic flavor in the conclusions of many, for it seems to limit the possibilities of education. However, since the number of cells thus created reaches the billions and there is evidence of what seems millions of undeveloped cells in the brains of men in their old age, it would appear that our present stock of possibilities are by no means exhausted. The nervous matter at any age shows what seems to be stages in growth of cell body, and along with the developed cells are to be found small cells, which neurologists have generally considered an undeveloped form awaiting structure or function, education or impulse, or whatever else the inciting cause may be, to call them into active service. Kaiser[3] took similar sections of the cervical region spinal cord in a new born child, a boy of 15 years and an adult. The number of developed cells in the new born child was 104,270; in the youth, 211,800; and in the adult, 221,200. The number of cells which came into function during the first fifteen years of life was therefore double the number at birth. From this observation it would seem, that even in the spinal system, the earliest to

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[1] Ueber das Gehirngewicht neugeborner Kinder. Wiener Klin. Wockensch., 1889, p. 34.

[2] Das Hirngewicht in Kindesalter, Archiv. f. Kinderheilkunde, 1897, pp. 164–192.

[3] Die Funktionen der Ganglienzellen des Halsmark, 1891.

mature, growth of new powers is significantly active throughout, until the adult period at least. Vignal[1] finds that the cells of the fœtus are distinctly smaller than those of the child and that they are more closely packed together. There is much indirect evidence for the conclusion that the cell bodies are increasing in size, though doubtless by such small increments as to elude observation by the methods employed, throughout the greater portion of adult life. Ramon y Cajal[2] has attempted to establish the principle that the size of a cell depends upon the number of its processes and collateral branches, that is, upon the number of other cells with which it is associated. Cajal has also offered the plausible theory that the growth energy which in early embryonic life is employed in cell division, passes, when this process ceases, into the work of forming the finer cell processes and collaterals and continues operative until senescence sets in, *i. e.*, to the number of other cells with which it is functionally associated.[3] There is also scattered evidence to indicate that the cell changes in chemical constituency with age. Dr. C. F. Hodge,[4] from a study of old and young honey bees and of the cells of a fœtus, a middle-aged man and a man of 92 years, concludes that there are changes of some character shown by difference in chemical reaction. Bearing upon this point Donaldson in his resumé of fatigue says: "In childhood the amount of stored material is small, large in maturity, and small again in old age. Hence the cells would by reason of this fact have the greatest capabilities for work in the middle period. Between childhood and old age there is, however, this difference, that while in the former the non-available substances in the cell are developing, not yet having material, those in the latter may become incapable of reconstruction."[5]

Growth of Finer Microscopic Fibres. It is a speculation to which neurological theories point, that the fibres which connect different parts of the cortex, one with the other, are most likely to be concerned in some way with association and the higher forms of neuroses. As early as 1840, Remak made a study of these "tangential" fibres and concluded that no material growth of these fibres took place beyond the eighth or tenth

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[1] Development des Elements du Systeme Nerveus, 1889.

[2] Archiv. f. Anatomie, 1896, p. 191.

[3] Studies bearing upon this question will be found in Vignal's Dévelopment des ëlements du System nerveux cérébro-spinal, Paris, 1889; Krohn, Jour. Mental and Nervous Diseases, 1892; Donaldson, Growth of the Brain, pp. 237–240, gives a resumé together with a cut reproduced from Vignal showing comparative sections of cortex from fœtus, child at birth and adult.

[4] Jour. Phys., Vol. XVII, p. 130.

[5] Growth of Brain, p. 314.

year. Exner, in 1881, and Tuczek later, made some study of the problem, and Fuchs found from 33 brains, confining himself to a single area in the posterior central gyrus, that in the outer layer of the cortex some tangential fibres appeared as early as the fifth fœtal month, and later in the lower layers. He thought the fibres reached their maximal number and size in the seventh or eighth year. Obersteiner much later reaches the same conclusion. In 1892 Dr. Oscar Vulpius,[1] of Heidelberg, made a more thorough and careful study from 22 brains distributed in age as follows: 32d fœtal week, 34th fœtal week, birth, 4½ months, 8 months, 11 months, 16 months, and 1¾, 2¼, 3, 7, 10, 16, 17, 33, 79 years. He cut homologous sections from the first frontal gyrus (left), third frontal gyrus (left), third frontal gyrus (right), anterior central gyrus (right), occipital lobe (right), and first temporal gyrus (left). After preparing and staining sections, he counted the tangential fibres in an area of a given size as they occurred in three layers of the cortex. The more important conclusions reached by Dr. Vulpius are that the tangential fibres begin in the outer and inner layer about the fifth month, and in the middle layer about the ninth month, that this growth does not cease in childhood, and that as late as the 17th year the increase of tangential fibres is marked; in old age an apparent decrease in number takes place; the greatest number of tangential fibres is to be found in the central motor region; poor nutrition seems to inhibit the growth of tangential fibres. Some of his results, as shown by charts, might be stated as follows: the inner layer in all localities and practically all ages has far the most tangential fibres and the middle layer the least; the relative number of fibres in each layer varies widely in each area, those of the central or motor region having the greatest number; the fibres of the inner layer develop their sheaths in all cases earlier, and in the motor sight and hearing regions, almost reach their maximum in number during the second year, while in the speech and other centers, there is a gradual increase until the eleventh year and a later gradual increment until the 33d year at least; the outer layer fibres follow in general the course of growth of the inner layer, but contain generally from one-eighth to one-half as many; the middle layer in no case makes an appreciable increase until puberty, grows most rapidly in the early adult years, and never contains more than a third as many fibres as the inner layer.

Kaes, in 1893, by a comparative examination somewhat similar to that of Vulpius, shows so conclusively that the development of fibres in the cortex, especially the tangential, is a

[1] Archiv. f. Psychiat. u. Nervenkrank, Vol. XXIII, 1892.

process still in active progress as late as the 39th year, that Edinger, who in earlier editions of his "Nervose Central Organ" denied the demonstration of this, admits in his latest edition (1896) that the principle has been established. In a later study, Kaes comes to the conclusion that at 40 years of age there is at least a partial arrest in the rapidity of growth of these fibres. The small number of brains compared, however, makes this statement of little value.

Dr. Hamarberg, unfortunately cut short by death in the midst of a most promising comparative study of normal and idiot brains, nevertheless made a definite contribution.[1] He compared homologous sections from the brains of nine persons ranging in degree with similar sections from normal brains, comparing the size, number and characteristics of the cells. In all cases the brains of defectives showed marked deficiencies. The developed cells were far fewer in number and of irregular and retarded development. His study leads to the conclusion that the idiot brain is one which has suffered arrest of development in some particular, involving larger or smaller areas of the brain, at some early period.

The more recent studies by Kaes upon fibre development entirely corroborate this conclusion of Hamarberg. In a recent contribution[2] he states conclusions from a detailed comparison he has made upon three brains; that of those of normal child 15 months old, a microcephalous idiot of 18 months, and a macrocephalic dwarf 25 years of age. The dwarf was the size of a child of about nine years of age, unable to speak or to understand language, and hampered by dragging movements of the limbs. Dr. Kaes measured the thickness of different layers of the cortex in several corresponding parts of these brains and gives interesting tabular results. He concludes that in devèlopment of the cortex the dwarf of twenty-five years of age has not advanced beyond that of the normal child of 15 months. The projection fibres of the central convolutions are better developed in the normal infant than in the dwarf, while the associational fibres which connect convolutions, marked in the normal infant, are absent in the dwarf. A feature that is common to both idiot brains is the manifest arrest by development of the second and third (Meynert)layers, and Dr. Kaes, from this and previous observations which he has made, feels justified in asserting that the development of this cortical region is essential to psychic unfoldment. A singular anomaly however is, that the external

[1] Studien über Klinik u. Pathologie der Idiotie nebst Untersuchungen über den Normalen Bau der Hirnrinde, 1890.

[2] Ueber den Markfasergehalt der Hirnrinde bei Pathologischen Gehirn. Deutsch W'chschr., Nos. 10 and 11, 1898.

tangential layer is broader and better developed in the idiots, than even in adult normal brains. He offers as a possible explanation the biologic fact that in the lower animal series this layer is larger, comparatively, than in the higher animals, and that in man it frequently appears only in rudimentary form. This external layer develops as low down the scale as reptiles, even prior to the projection system, and Dr. Kaes holds the opinion that we must consider it the precursor or oldest form, on the sensory side, of the projection system. Applied as an explanation of the anomaly described, Dr. Kaes takes the view that these idiots are arrested in development at an early biologic stage and the relatively large amount of tangential fibres represents persistence of an old type. Further he finds that the microcephalous infant had suffered a complete arrest of the development of the fibres of the central convolutions while those fibres most directly in connection with smell were retarded the least, which is significant in view of Edinger's evidence that the apparatus of smell is the oldest of cortical structures, appearing even in reptiles.

This theory of origin regarding the outer tangential layer, put forth by Kaes, agrees neatly with that of the school of Ramon y Cajal which has contended that sensory impulses are received in cortical cells by way of the dendritic processes extending upward to this layer.

Speculatively regarding the two theories, we might say that the external layer is the older path but that in more highly evolved forms some new avenue of approach has been established; that idiots tend to revert to this more ancient path which functions only a low order of psychosis.

While this class of studies, dealing with the growth of the finer microscopical nervous structures in later life, is not as numerously represented as could be desired, yet the results seem sufficient to establish the fact that the finer nervous structures continue to grow until a late period of life; and further, that there is some definite order in their progressive development. These conclusions, when worked out in more accurate detail, will serve to banish many of the fatalistic inferences which psychologists have been prone to conclude from neurology, and to extend the limits and importance of education.

The Order of Functional Maturity. The conclusion has now passed into general acceptance that when a nerve fibre acquires its fatty sheath, or becomes medullated as is said, it is then functionally mature. No nervous function is ascribed to the sheath. It serves the same purpose, it is believed, that rubber covering serves for electric wires—it prevents wasteful radiation of the nerve current.

The significance of medullation, once established, becomes a key of great value in determining the order in which the various parts of the nervous system develop. Studies in this direction have been pursued most notably by Professor Flechsig, the psychiatrist of Leipzig. His investigation upon the order of development in the parts of the spinal chord was published as early as 1876 and a continuation of this line of investigation in the brain has appeared in very recent monographs.[1] The spinal chord consists of a core of gray matter surrounded by vertical bundles of nerve fibres. These various bundles connect different portions of the nervous system.

Flechsig found that the class of nerve fibres first to take on their medullary sheaths are those connecting neighboring centers in the cord, and those concerned in receiving and discharging simple reflex reactions. This medullation process begins in the latter half of the fifth fœtal month. Then follows the medullation of the short columns connecting different levels of the cord, and presumably, therefore, concerned in local reactions of the cord itself. The columns of Burdach follow, and still later that of Goll, which conveys the sensory impulses, received chiefly from the periphery, upward to nuclei in the medulla and are thence transmitted to the cortex ; still later the cerebellar columns conveying impressions to the cerebellum, having to do with equilibration, are developed. The pyramidal columns which discharge voluntary impulses from the cortex of the brain downwards do not mature in the cord until about the time of birth and later. This order of development of the spinal columns is of important significance to the problem in hand, for it shows that the order in which the different strands of the spinal cord reach maturity is the order of racial unfoldment. The simple reflex mechanism is the earliest in biologic development of the nervous system, and, as shown, is the first to mature in the development of the individual. Voluntary movements regulated by the cortex are the most recent in racial development, and, the pyramidal tracts which convey these impulses, are the last of the spinal columns to reach maturity. We have here, therefore, the illustration of the principle that in the development of human nervous functions, the first mechanisms to mature are those which are fundamental and racially the oldest, and that the order of development proceeds from these to those which are of more recent evolution.

The spinal cord of the human infant at birth, Flechsig finds, is completely medullated with the exception of the pyramidal (motor) columns. Medullation extends to some extent in the

[1] Gehirn und Seele, 1896 : Die Localization der Geistigen. Voränge inbesondere den Sinnesempfindungen, 1896.

medulla oblongata and in the pons, but the entire cerebral hemispheres are yet immature with the exception of a few traces in the internal and external capsules and in the lenticular nucleus. The new-born human infant is therefore a creature not unlike Goltz's dog whose cerebral hemispheres were extirpated. This dog, it will be remembered could react, by means of his spinal mechanisms, to external excitations of pressure, light, sound, etc., but was utterly incapable of originating movements or of profiting by memory.

Flechsig's most recent studies have attempted by the same neurological method, to trace the order of development of the various bundles of fibres in the brain proper. In the monograph *Die Localization der Geistigen Vorgänge inbesondere der Sinnesempfindungen* (1896), he gives the results of his researches upon the sheaf of sensory fibres which, originating (indirectly) in the spinal cord, conveys impressions through the internal capsule to the cortex. He finds that it is composed of three separate bundles, each maturing at a different period. The first bundle begins to mature just before birth. The largest portion of its fibres go directly upward and distribute themselves over the two central convolutions. This is a fact of extremely important significance in substantiation of the evolutionary principle. Of all localization of the brain, that of these convolutions is most clearly established in detail. They represent the older fundamental parts of the organism—kinæsthetic and tactual sensation of the arms, legs, trunk and of bodily feeling generally. The region they enter is the one which, on the motor side, controls the most essential and chief movements of the body, as the electrical experiments of Ferrier, Horsley and others upon monkeys have demonstrated. A small branch of this first system disappears in the direction of the occipital (visual) area, but Flechsig is unable to assert positively that this branch contains optic fibres. In the first month after birth a second bundle of this sensory sheaf, appearing in the inner capsule from the lower levels, matures in the direction of the cortex. A large part of these fibres find their destination in the same areas as those of the first, while another part turns inward and distribute themselves along nearly the whole length of the gyrus fornicatus on the mesial side. According to Ireland,[1] resting his conclusion on the experiments of Ferrier, Horsley, and Shäfer, this region represents sensations of touch and temperature, but its exact function is yet doubtful. The third of these sensory bundles does not mature until a very much later period, varying from one to several months after birth. One part goes directly to the foot of the

[1] Journal of M. S., Jan., 1898.

third frontal convolution (the Broca center for speech). Other smaller bundles are distributed to the first and second and third convolutions and also to the gyrus fornicatus. The most significant feature is that Broca's speech convolution begins development at a very much later period than other parts of the great areas concerned in general bodily movements. The order of development of the fibres in their approach to the cortex through the internal capsule is regulated by the same principle, we therefore see, as those in the spinal cord — those which perform the oldest and most general functions mature earliest.

The first of the special sense centers in the cortex to mature, according to Flechsig, is that of smell, which, according to Endinger's studies, is the first sense center to be evolved in the biologic scale, appearing as low as reptiles ; the last to mature is that of hearing. The process of medullation of the fibres leading to and from the sense centers takes place rapidly, and by the end of the first month of human life, all of them show some evidences of maturity.

Up to this point Flechsig's anatomical contributions are accepted generally and much that he has put forth on these lines has been corroborated by other neurologists. But in the matter of the fibre connections of the cortex with lower nervous centers, he offers a revolutionizing contention in brain localization and his claim is now under the fire of criticism and dispute. Heretofore it has been the accepted theory that the entire cortical area sent or received fibres to and from the lower centers. Flechsig, from his examination of infants' brains, declares this is not true. Only about one-third of the cortical area at the end of the first month shows these descending or ascending fibres. Then medullation begins to appear in the other areas, in the frontal portion, in the large posterior parietal area and in the Island of Reil, covering in all two-thirds of the human cortex. But contrary to expectation, based upon the supposition of previous methods of determination, these medullated fibres do not come nor go from the lower brain centers. They give no evidence of a peripheral source or destination. They do not follow the course of the fibres developed in the first month of life. On the contrary, Flechsig contends, the source and destination of medullated fibres of these larger cortical areas are in the sense centers previously developed — those of sight, hearing, touch, smell and taste. Since they are of different anatomical connection and direction, the conclusion is necessary that they must have a different function. Flechsig leaves his anatomy at this point to offer the plausible speculation that these large centers have for their function the association, and the superior directive power of inhibitive interference upon the areas of sense impressions. "Only one-third of the human cortex," he concludes with some pardonable eloquence, "stands in direct relation with the processes which bring sense impressions to consciousness and excite the muscles and mechanism of movement; two-thirds have directly with these nothing whatever to do. They have another, a higher function" — the function of knowledge, of interpreting experience, of the æsthetic sentiments, of the scientific decisions, of the moral judgments, etc. Through disease of these highest association areas, if we may follow Flechsig in some daring speculation, the individual is thrown back for the determination of his conduct upon the sense or lower centers. Such, he suggests, is the effect of alcoholic intoxication, and other more permanent forms of mania. It is undisputed that in idiots and imbeciles, Flechsig's areas of association are notably small. Flechsig goes further and claims upon anatomical evidence that in monkeys instead of two-thirds of the cortex being devoted to these associations, there is but one-half; among carnivora, these centers are very small and decrease as we descend the scale of mammals, disappearing entirely in rodents. It might be well, since Flechsig's conclusions are now being tested by criticism, to draw a line between his anatomical contributions and his speculations. Unquestionably he has conclusively shown that certain bundles of fibres, representing certain more or less specific movements, mature at distinctly different periods. Regarding his association centers, it must be admitted that Flechsig has here contributed positive data of anatomical observation that the sense centers are indirectly associated in a common area. As positive data, it cannot be contradicted by theory or mere argument — we must wait for positive data of contradiction.

Dr. Ross in his *Diseases of the Nervous System* was perhaps the first to attempt a distinction in the nervous system between structures which in function antedate the human form of the organism and those which have been added during the period of human evolution. He says: "The portions of the nervous system which man possesses in common with lower animals and which are well developed in the human embryo of nine months, I shall call the *fundamental* part, and the portions which have been superadded in the course of evolution, which differentiate the nervous system of man from that of the highest of the lower animals, and which are either absent in the human embryo or exist only in an embryonic condition, I shall call the *accessory* part of the nervous system." Dr. Ross points out that the main movements which distinguish man from the lower animals are those which he has acquired since he adopted the erect posture—the varied movements of the hand in prehension and tool-using which developed after the hand ceased to be merely a foot; the movements of articulatory organs concerned in speech, and movements of facial expression. Dr. Ross, by this suggestive juxtaposition of fundamental and accessory physical parts in the human organism, with the fundamental and accessory mental powers of man, has opened a field of inquiry rich in suggestion for psychology and education. Are these accessory movements of the hand and the articulatory organs, in some intimate connection with that mentality of man considered as accessory developments to those of the lower primates? Have these accessory elements, by virtue of their comparative newness, more instability and plasticity, and are they therefore more subject to education? Lastly, and most important in the development of the individual, is the order the same as that of the race, so that from infancy to manhood we have a procession of developing parts beginning with the oldest and most fundamental and ending with the newer and accessory? Granting, for example, that the physical development follows this order, does mentality as well? If so, and if we can follow this order of development in some detail, we should have a principle that long has been needed for clearer visualized thinking in psychological and educational science.

We must not neglect in this very brief consideration the very probable theory, happily named by Baldwin[1] the "short-cut" theory, by which development in individual man, by ages of modification, cuts across lots, thus escaping many needless bends and turns in the road evolution has actually travelled. Unless we accept this modification it would be impossible to explain many anomalies; for example, the fact which Gratiolet has pointed out that, while in the embryonic development of the ape, the tempero sphenoidal convolutions (embracing the human auditory center) appears first and the frontal convolutions last, in man the order is reversed.

Man does not complete his fundamental development at birth. If we are to accept Flechsig's association areas as the centers of human reason, we find these parts, anatomically, far down the vertebrate scale. From an objective study of human activity as illustrated by movements, the suggestion would be that these accessory structures are delicate modifications of existing structures,—new duties added to old forces. Ross thinks we have indirect evidence of these accessory formations in the huge development of the prefrontal lobes, which have pushed the posterior parts of the brain over the cerebellum, made the Rolandic fissure seem further back, relatively, and forced the posterior limb of the Sylvian fissure into a more horizontal position.

[1] Mental Development in the Child and Race, p. 21.

Flechsig's contributions of data go far to enrich and substantiate the theory of Ross by showing an evolution in the order claimed. But Flechsig's facts deal wholly with infancy and must be taken merely as the beginning processes of development.

From the evidences of late growth of fibres shown by Kaes and Vulpius, and of cell bodies by Hamarberg, there is justice in assuming that these processes continue until late in life under regulation by the principle which requires the more general and fundamental structures to develop before the accessory. If this indeed be true, then it is clear that the historic pedagogical contention, stated in the preface, that the order of instruction should be regulated by the order of internal development of the mind, rather than by the logical order of the subject-matter studied, rests upon a substantial basis.

The Level Theory of the Nervous System. The conception of the nervous system as an undifferentiated unity, such as pervades the popular notion of mind, is not a view that finds substantiation by modern investigation. The notion that all our actions are dictated from a single center, the brain, is at best but half a truth; many actions which have every appearance of good sense are regulated entirely within the spinal column; and some from within the walls of the abdomen. The lower orders of animals have no brain ganglia, and the lowest vertebrates no cerebrum. Man epitomizes the products of biologic history, and from an evolutionary standpoint we should expect a nervous system of added parts instead of a homogeneous organ. All positive evidences from the sciences of anatomy and physiology, and pathological phenomena as well, go to support the evolutionary view of the nervous system of parts, correlated and closely associated, but nevertheless preserving a degree of relative independence.

It was some thirty years ago that Dr. Hughlings Jackson, the eminent English pathologist, made practical application of the evolutionary theory of the nervous system to the diagnosis and treatment of epilepsies and mental diseases. Such has been the practical success of this application, that the so-called Hughlings-Jackson three-level theory is now the established basis of English diagnosis, and, in the words of a reviewer,[1] it has established system where previously all was chaos.

Jackson conceived the nervous mechanism as composed of three systems arranged in the form of a hierarchy, one upon the other, the higher embracing the lower yet each preserving

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[1] Dr. James Anderson in Hack Tuke's Dictionary of Psychological Medicine.

for itself some degree of exclusive independence. The lowest level is composed of those cell structures which receive impulses without physiological break, from the periphery or non-nervous tissues and those which discharge impulses into such tissues to produce movement. This has also been called the reflex level for it represents the type of simplest reflex and involuntary movement. Jackson localized these structures in the grey matter of the spinal chord, medulla and pons. His second, or middle level, comprises those structures which receive sensory impulses, not from the periphery nor from the non-nervous tissue directly, but from cells of the lowest level; the motor cells of the middle level discharge, not into non-nervous tissue directly, but into the motor mechanisms of the lowest level. If we say that the lowest level "presents" impulses, then, in Jacksonian phraseology, the middle level "represents" them. Anatomically, Jackson included in the range of these middle level structures the cortex of the central convolutions, the basal ganglia and the centers of the special senses in the cortex. Evidence for such a level lies in the fact, now proven by the process of secondary degeneration of nerve fibres, that there are no fibres extending continuously from the periphery or muscalature to the cortex nor in the reverse direction. In all cases they extend as continuous fibres only to the vicinity of cells of the reflex level in the cord, medulla and pons, as Jackson held. Jackson's highest level, as the topmost layer of the hierarchy, bears the same relation to the middle level centers as the middle to those of the lowest level. He presumes upon no continuous connection between highest and lowest level—the middle level structures mediates between them as a system of relays. The highest level, therefore, "*re*-represents" the external world through the double mediation of the middle and lowest levels. Jackson had no anatomical evidence in positive proof of the actual existence of highest level structures. His ground for it was physiological and a conclusion necessary from practical diagnoses of epilepsies. He localized it by accepting Broadbent's hypothesis. Now it strangely so happens that Broadbent's[1] hypothesis forestalls, both in its localizations and assumed functions, Flechsig's "association centers." In function and localization, therefore, Jackson's highest level and Flechsig's alleged association centers are practically identical.

According to this hierarchal arrangement of the nervous system the lowest level, as the simplest, oldest, most fixed and non-plastic, contains mechanisms for the simple fundamental movements in reflexes and involuntary reactions. The middle

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[1] For original article see Med. Chir. Trans., 1872, p. 178-9; Jackson's acceptance, Brain, 1879.

level regroups these simple movements by combinations and associations of cortical structures in wider, more complex mechanisms, producing a higher class of movements. The highest level unifies the whole nervous system, and, according to Jackson, is the anatomical basis of mind. "The highest level centers," says he, "are nothing else than the centers of universal and complex representation, or what is the same thing, universal and complete co-ordinations, or, using old-fashioned language, they are the whole organism."

Jackson's theory is thoroughly evolutionary in its essential conceptions. "What are the lowest levels," says Jackson, "are centers for the simplest movements of the limbs, which become evolved, in the highest centers, into the physical basis of volition. What in the lowest levels are centers for simple reflex action of the eyes and hands are evolved in the highest level, with the physical basis of tactual ideas. What are the lowest centers for movements of the tongue, palate, lips, etc., as employed in eating, swallowing, etc., are, in the highest centers, evolved into the physical basis of words, as symbols serving abstract reasoning, what are the lowest centers for circulatory, respiratory and digestive movements, in the highest centers, are the physical basis of the emotions. So to speak, the lowest level does menial work; the highest level, evolved out of it, becomes in great degree independent of it and is the anatomical basis of mind."

The three-level theory grew chiefly out of the need of a practical working hypothesis in the diagnosis of mental diseases, and as such it has proved serviceable in pathological practice. In epilepsies, due to affections of the lowest level, there are spasms of the reflex movements without necessarily involving higher and more complex co-ordinations, as, for example, respiratory fits. The middle level epilepsies are of a more complex order, originating in some point of the extreme periphery and extending in directions that are found to agree with adjacency of centers for these movements in the cortex; loss of consciousness is frequently a subsequent, but not necessary accompaniment. Jackson localized the seat of middle level epilepsies in the Rolandic convolutions, and so accurate was this conjecture, that in the light of subsequent studies in brain localization, trephining of the skull and removal of the diseased portions of the brain has become a successful mode of treatment. In 1895 Starr[1] reports 350 cases of trephining with a large percentage of successful results. Laurient earlier reports upon 102 cases of trephining for middle level epilepsy as follows: cured, 54; improved, 20; not improved, 17; made worse, 2; died, 7.

[1] Brain Surgery.

Very different, however, are the forms of *grand mal* and *petit mal* epilepsy which Jackson diagnosed as affections of the highest level. There is a spasm, not in a single part of the body, but of the whole, and consciousness is lost at the outset.

Pedagogical Application of the Level Theory. Pathological practice in the diseases of dissolution, or "devolution," of the nervous system now accepts the essential conception of the Jacksonian theory as a successful working hypothesis, recognizing, however, that it is a general scheme rather than a detailed plan of proven facts accurate in detail. Its applications have, however, never yet been made to psychology and pedagogy. Education deals with the normal evolution of the nervous system. It therefore in a sense takes a complementary view to that of nervous pathology. May it not be that the introduction of the Jacksonian view of the nervous system may prove as serviceable to education as a working hypothesis, as it has in pathology? In crude outline we must recognize in this hierarchal scheme of the nervous system, the analogy of its phylogenetic development. In the lower invertebrates, we find, not a centralized nervous system with a cerebral or even spinal central stations, but a loose system of local ganglia regulating, in more or less independent manner, special movements of the animal. In higher orders chain ganglia appear with a growing approach to centralization. In vertebrates we find the chain system transformed into the spinal system and within the cranium are ganglia of the special sense organs, developing in complexity and centralization as we go up the scale. Flechsig's highest association centers, presiding over higher reason, if we accept them, extend as a tapering tongue far down the mammalian scale. The human nervous system, therefore, from this view point is the jointed product of evolutionary increments. It sums all stages of its historic evolution. Within it are preserved the primitive forms of nervous control as well as the last products of evolution. The reflex level finds its analogy in the lowest forms of life; the cerebro-spinal system represents a later addition; the highest level is essentially a human accession. The progress of development upward through the levels is a progress from simplicity to complexity, from that which is oldest racially to that which is newest, from that which is fixed and unyielding to the environment, to that which is plastic and yielding to environmental changes. Is it possible that in mental and physical growth from the human infant to maturity we may trace, with practical suggestion and profit to education, the phylogenetic joints of his historic evolution?

From the order of development in maturity of the fibre bundles of the spinal cord and brain, it is conclusive that each bundle has its special period of immaturity, of plastic growth, and finally fixed maturity when modification is difficult or impossible. This middle nascent period is the period for education. "We know," says Clouston, "that each center has its own nascent or growth period, which is sometimes very short, as it must be in the center in which movements of sucking are co-ordinated; and sometimes very long as in those in which we co-ordinate the movements of the hand, from its first feeble grasp up to its consummate achievements in making and shaping."

On the side of external movement we see corresponding phenomena in development. The cord reflexes appear and perfect themselves, largely in early infancy, it is true, but nevertheless they continue to develop until a comparatively late period. Certain reflex movements of the eye, opening or closing upon stimuli of light, moving upward and downward, one side to the other, are mature in the early hours of life; but the capability of a specific object in the field of vision to control and direct these movements, is not manifest generally for several weeks, and an act of volitional control which we may regard as an interference of the highest center does not appear for several months. The infant can grasp with its fingers in the first hours of life, but it is several months before it uses the thumb in its grasping movement. Many of the most delicate movements, accomplished by nicest adjustments of the highest centers, do not appear until very late in childhood. On the other hand, many of the eye adjustments pass to the control of the higher centers, undoubtedly, in infancy. Therefore we must carefully avoid the notion of the maturity of all the nervous processes occurring at a specific time or period. We must on the contrary conceive the process as one occurring separately in many thousands of activities depending upon as many neural developments, each pursuing its progress from birth to senescence, reaching different levels of activity at different times and at different rates of progress. However, with the clear recognition of this principle, and the manifest incorrectness of the conception that would lead us to say in an absolute sense, that the reflex level, as a whole, matures at a certain period and then rests; that the cortical sense-centers, as a whole, next mature, and finally that the highest level matures; still facts may warrant us in concluding that certain general periods may be characterized by predominance of nascencies in a given level. Thus it certainly may be said that in infancy the nascencies of the lower level outnumber those of the middle and higher, that in childhood up to puberty the sense-center nascencies predominate, though lower level processes continue to appear and a fair number of highest level nascencies occur; and that finally in the adolescent period highest level growths predominate.

There are many facts which go to support this tripartite progress of nascencies, in a loose sense. Insanity, for example, is rare in children under fifteen years, and Mercier explains this fact on the ground that children under the pubertal age do not yet possess mature higher centers. Insanity under modern interpretation is an affection of the centers of the highest level. Disregarding senescence, it has been found that the greater number of insanities occur in the later ages of maturity,—in men from 40 to 60, and in women from 30 to 50. However, Mercier is only loosely correct in saying that insanity does not occur until after puberty, and the exception confirms the principle put forth that the highest center is slowly maturing in some fields of activity from infancy through childhood. It is not so frequent, probably because there are fewer parts matured, and perhaps these, since they are the earliest found, are the oldest phylogenetically, and hence more resistant than many later formations. According to Boutteville, the proportion of insane children to insane adults is as follows: From 5 to 9 years, 0.9 per cent.; 10 to 14, 3.5 per cent.; 15 to 19, 20 per cent. Winslow finds only eight children under ten years of age among 21,333 insane patients. But with the beginning of puberty there is developed a variety of psychic phenomena, which, while only temporary, are none the less to be classified as within the borderland of insanity,—irritability of temper (*i. e.*, lack of inhibitive control by the highest centers), morbid notions ranging into hallucinations, etc. Insanity in children when it occurs, according to Ireland, is generally an after-effect of certain diseases, tubercular meningitis and fevers which, we can readily understand, tear down the tissues of the highest centers. The gradations of epileptic diseases indicate a growth by periods. Epilepsy in all its forms, may perhaps be regarded as a disease of nervous instability. A development upward through the levels has been traced. Certain forms as the respiratory infantile convulsions and other attacks of the lowest level are most common in infancy; Jacksonian epilepsy of the middle levels predominates later in childhood; genuine epilepsy is most frequent later still. Still, all varieties do occur to some extent in the early period, illustrating the probable fact which has been pointed out that all systems commence to grow at an early period. Gowers has shown that out of 1,450 cases of various epilepsies 29 per cent. began in patients under ten years; 46 per cent. between ten and twenty years; 15.7 per cent. between 20 and 30; 6 per cent. between 30 and 40; and 2 per cent. to 1.5 per cent. after 40.

As a frank speculation, may we not ask whether it is not plausible, in a loose sense, that the period of predominating culmination and extreme nascency of the highest level, unfolds at a time beginning roughly with puberty and lasting throughout the earlier years of adolescence: whether the period of culminating nascency of the middle-level system does not begin about the second year of life and gradually mature throughout the early ages of childhood, reaching a period of ripened but slow growth in the three years just preceding puberty: whether the reflex system is not most active in earliest infancy, and as we see in the gradual maturity of reflexes reach its maturity about the second year?

In an unconscious but nevertheless clearly established way, these three periods have for practical purposes always been distinctly insisted upon by the popular mind. Infancy has been recognized as a period for learning to creep, to walk, to maintain the equilibrium and to use hand, arms, and legs in the countless movements that later become reflex. Childhood, by ancient and familiar dogma, is the period for training the sense-centers. No period, however, has been so clearly recognized as that of the nascency of the highest system in adolescence. It is a common statement that it is not till a child is thirteen or fourteen years of age, the pubertal period, that he is capable of rational thought and reason. The school has always insisted upon this, giving memory topics in the earlier years and reserving the rational study, requiring higher correlation for the later period. In all religions, civilized and savage, there are religious rites, perhaps dependent in origin on sexual changes, but, nevertheless, changes which are clearly conceived as psychic as well, recognizing that the child takes on at this time the adult's logical thought. The confirmation services in our established churches are evidences about us, and in evangelical churches there is a prejudice against accepting a religious judgment until after the child is thirteen or fourteen years. On the other hand, this is the period the child himself chooses to make them. Rousseau clearly expresses a wide-spread sentiment, when he asserts, that until twelve years the child should grow practically wild, and Aristotle in his ideal state would begin the first really psychic judgments, based on higher association, at fourteen.

May we indeed not go still further, and, upon a basis of ontogenetic and phylogenetic parallelism, speculatively raise the question whether or not these nascencies in the reflex, middle, and highest levels do not carry with them specific biological characteristics; whether it is not true that in infancy we do find evidences of the rudimentary instinct of spinal life in a biologic sense; whether in childhood, the instincts that have been most closely associated with middle-level activity in an evolutionary sense do not now predominantly appear; and finally whether we may not find in adolescence the appearance of certain higher atavistic associates of the highest level, more characteristic of man's higher and later development. At least in a crude general way is it not probable the methods of learning new things, of thinking and reaching conclusions in action and even in thought do not pass through these three stages of growth, so that tendencies, interests, and instincts developed by a lower system built by a subsequent growth of fibres from the highest system tend to be replaced by higher level forms in a natural way? It is more than a merely plausible hypothesis that if the structure governing a given nervous reaction in an activity is carried forward by evolution from a lower to a higher organism, the reaction itself of this transmitted structure must also tend to be reproduced, preserving amid accessory human types of reasoning the vestigial tendencies of earlier racial habits. And it is more than merely plausible, from all we now know of the structure and processes of the nervous system, that the accessory or highest human types of action and thought only reach this highest stage by passing through, in infancy and childhood, the lower level types of this process. We must not place emphasis upon the number of levels which the Jacksonian theory has employed, for that has been a rather arbitrary assumption. There may be many levels. The central conception is that the higher processes are formed by combination of elements and structures of a lower process already existing. Children frequently persist in following some strange, useless or even savage interests quite foreign to our civilization. Upon this doctrine of development by levels, these strange and useless experiences nevertheless may be essential as a platform, out of which a higher co-ordination, useful for modern life, may be reached. The intermediate stage or level may be useless or even inimical to our civilization, but yet as a link in evolution, be none the less essential.

A system of education following the order of developing nascencies in the parts of the brain would, in all probability, find itself in opposition to many of the methods of the present curriculum of the primary school. At least the present practical pedagogy is based largely upon the logical cleavage of the subject studied, and has given little or no attention to the order of development by nascency. If the abstract reasoning is largely a process of association of centers of the highest level, and if, as facts seem to point, the highest level does not reach its stage of predominating nascency until the adolescent period, then the so-called reasoning process, as it appears in adult life and in childhood, cannot reasonably be presumed to be identical in essential character. The reasoning of the adult must involve a large area of centers, and a more intricate concatenation. Yet school practice, relying partly upon notions of metaphysical rationalism and folk-thought has naively assumed that the process by which children and adults reach conclusions are identical.

From Fundamental to Accessory in Movement.

Muscular movement is the complement of nervous activity. If there has been an evolution from fundamental to accessory forms of structure in the nervous system we must expect to find a similar evolution in the character of movements. Facts answer fully these requirements of theory. The movements which are regulated predominantly by the accessory structures of the nervous system show certain characteristics distinctly differing from those regulated by the fundamental parts of the nervous system. An illustration of accessory movements in the sense of those which are not possessed by animals lower than man is offered by the complex capabilities of the human hand. To bring out the characteristics of the accessory hand movements as distinguished from the fundamental movements, we may compare them either with fundamental movements of the human body, *e. g.*, the trunk movements, and with fore-limb movements of lower animals. The first comparison has been carefully made by Dr. Mercier, though with no attention to evolutionary significance, in his distinction between "central" and "peripheral" movements. By central movements he means those made by the trunk and more central portions of the body[1], and by "peripheral" he means the movements made by the hand, articulatory muscles, etc. But the terms in the comparison chosen, practically coincide with "fundamental" and "accessory" respectively, since the trunk movements are those which man has in common with lower animals and a large class of hand movements have been added in human experience, though another class are clearly fundamental. Dr. Mercier points out in the first place (1) that the trunk movements are few and resemble one another in kind, while the peripheral movements are countless in variety and number. The movements of the trunk are limited chiefly to leanings, some slight ability to rotate, and to the respiratory function. "With each step that we take towards the periphery, the number of movements that can be executed and the amount of difference between these movements increases, until at length when the periphery is reached, the number and variety of movements becomes enormous. The area over which the hand can be moved is almost as large as that of a sphere whose radius is the length of the arm, and the hand can reach three-fourths of the points between the shoul-

[1] The Nervous System and Mind.

der and the area thus marked out." In order to realize the innumerable positions members of the extreme periphery may take, we have but to note a pianist's hands and fingers in movement. (2) The most significant distinction to which Dr. Mercier draws attention is that in the association of two or more movements, the distinctive tendency of central muscles is to make them simultaneous or alternating, while the accessory muscles are distinctively capable of long and complex sequences. The legs in walking alternate and there is even bilateral tendency in using the whole area for the other arm to move simultaneously. Compare with these the power of the hand in writing, or the articulatory muscles in speech to maintain long series of movements in accurate sequence. The first term of the series being stimulated the other terms follow in an accurate order and nicety which is marvellous when we attempt to analyze them. Consider for example the habit of sequence which is developed in the fingers of the pianist. (3) The central movements are crude in any work requiring precision and delicate co-ordination. The central movements enter as associates into these co-ordinations by providing steadiness, but the finer movements are performed by the periphery. (4) The peripheral movements bear to the central the relation of the special to the general. We cannot use our fingers in writing till by the central movements the arm is brought into position and held steadily. We cannot speak without the general movements of breathing which force the air through the larynx. The peripheral movements, aided by their power of acting successively and with greater complexity, perform special feats.

It would be a faulty explanation of these striking differences in the characteristics of central and of peripheral movements to assert that the differences are due a larger number of muscles in the hand[1]. The number of muscles in the entire arm exceed those of the trunk very slightly. The marvellous adaptability of the hand can only be explained on the ground that the higher levels of the nervous system combine the lower level movements into the countless new complexes and introduce the features of sequence, precision, etc., which for the fundamental levels are practically impossible.

Many movements of the hand are of course fundamental, and the theory of superposition in the governing nervous structure is prettily shown by the phenomena of certain nervous diseases. General paralysis that begins in the highest

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[1] Quain's Anatomy, p. 186, gives the number of muscles in the body as follows: Head and neck, 75; vertebral column, 51; upper limb, 58; lower limb, 54.

centers is accompanied in slighter attacks with almost imperceptible interference with precision; the patient is not able to execute the finer delicate movements. As the disease spreads downward, these more general, more complex, more precise movements are lost layer by layer as it were, from accessory to fundamental, from peripheral to central, from highest to lowest level, from the products of latest evolution to those of the older. Such devolution may be illustrated in the early loss of writing without appreciable loss of fundamental movements of the hand; by the early loss of speech without loss of eating or swallowing movements of the throat, nor any paralysis of the tongue and lips. In downward progress of disease—in devolution so to speak,—the loss of higher level centers results in loss of peripheral or accessory movements, frequently leaving the fundamental movements quite unimpaired.

It remains briefly to compare the movements of the human hand with the movements of the fore limbs of lower animals for the purpose of noting that these characteristic differences between higher accessory human movements and those of animals are the same that exist between the accessory (peripheral) and fundamental (central) movements in the human body; and secondly, to offer further evidence that the explanation of these differences parallels the differences between the accessory and fundamental levels of the nervous system.

However different the movements of the fore limb of man and brutes, however varied the degree of complexity and the diversity of purpose for which these movements are employed, nevertheless the fundamental structure in all is singularly similar.[1] Place drawings of the skeletons of the human hand and of the fin of a whale side by side and ordinary observers will require the printed names underneath to distinguish them. The muscular framework offers greater differences it is true, but the difference in the arrangement of muscles between a monkey hand and a human hand offers scarcely any proportionate hint of the real differences in their capabilities of movement. There is always a cluster of bones forming an ankle or wrist, and proceeding peripherally from it a series of bones, actual or rudimentary, forming what may be called rays. All originate from the primary purpose of locomotion. M. Bernard suggests the crocodile as a living example of this primary type, by whom the fore as well as the hind limbs are used solely for locomotion, though if we choose to go further

[1] For an excellent comparison see M. Bernard, Pop. Sci. Mo., Feb., 1898.

back we find the fin of the fish similarly used. Now, in most of these early types, the movements are very few and simple, practically limited to movement forward and backward in a single plane ; there is practically no rotatory movement either in the shoulder or other joints, and the digital extremities are not used for grasping except in a very rudimentary way. As we go up the scale of evolutionary differentiation we find new movements and a few new anatomical modifications, but the former are in far larger proportion. Bears develop claws, and with them a clutching movement for climbing trees or holding prey ; ungulates, for rapidity of flight ; carnivora, for rapidity and strength in pursuit, endurance and holding or tearing prey. But in all these modifications the number of different movements is extremely few ; they are without complexity, dominated by the character of simultaneity, making slight use of the principle of succession ; they are without relation, and are all executed nearly in the same plane. In the movements of clutching, tearing, etc., there is no independent movement of the digits, but these are merely transformed into a sort of claw, and the real work is done by the more central muscles which draw this hook in one plane, thus useful in tearing, pulling, digging, etc. Moreover, in all animals below the primates, with few exceptions such as birds, rodents, etc., the movements which are not those of locomotion are merely incidental and reach no important degree of complexity. The toes in the great mass of common carnivora and ungulates are used for walking ; the joints stiffen and, as in the case of the horse, some atrophy and practically disappear. With the arboreal life of the Simian species, a new environment has worked wonders with the limbs. In life among the branches of trees and the necessity for dexterous and agile movements of the limbs, the monkey family seem, compared with the lower animals, to have made a progress that amounts seemingly to a difference in kind. In point of form of hand and arm movements, though not in perfection, complexity, and in ability to execute series of successive movements, the apes probably are nearer akin to man than to the lower animals.[1] Apes have to some extent the power of bringing the thumb into opposition,[2] but the ape grasp, as some one has said, is adapted for seizing a cylinder, while man's grasp is adapted for seizing a sphere as well. Compared with man,

[1] Broca, Revue d'Anthropologie, 1872, p. 26, concludes that anthropomorphous apes approach more nearly the bipedal than the quadrupedal type.

[2] See Turner. Pres. Address before anthropological section of the Brit. Ass'n for Advancement of Science. Nature, Sept. 2, 1897. Dr. Hepbren, Jour. Anat. and Phys., XXVI.

Broca[1] found that the arc of rotation of the forearm of certain monkeys is not more than 90 degrees, while, according to the same investigator, it reaches 140 in the chimpanzee and 180 degrees in man.

It is unnecessary to multiply examples. It is evident from this brief survey that progress in evolution of hand movements in the biologic scale has been from extreme fewness in number to infinite variety, from simplicity to complexity, from clumsy inaccuracy to precision, from simultaneous associations to those which constitute long series in sequence, from the general to the specialized. Secondly, it is evident that the slight differences in bony or muscular structure are far inadequate to explain these enormous differences between accessory and fundamental. The jaws, teeth, tongue and palate of lower vertebrates are not so radically distinguishable from those of men to account for the rapidity, complexity, marvellous precision, accurate co-ordination and successiveness involved in human speech. Yet a civilized man uses a score of thousand words or more, each requiring a special and appropriate set of movements, different from all others; and moreover he throws these together in sentences requiring successive co-ordinations of long sequences with marvellous precision and rapidity. When we attempt to measure the gap between man and the lower animals in terms of power of movement, the wonder is no less great than when we use terms of mentality. We are forced back again for an explanation of this marvellous complexity of adjustment to the nervous system, and to conclude that the difference in associational capability between the accessory and fundamental levels must indeed be significant. A chapter essential for the completeness in the educational application of the principle which has been thus treated, would attempt to show at this point that the individual from infancy to maturity passes through stages of movement from those which possess the fundamental characteristics to those which are accessory. This discussion, however, must be reserved for a subsequent place.

Relation of Accessory Hand Movements to Human Intelligence. In previous sections the evolution of the nervous system and the evolution of movement have been traced separately. The present section will deal with data suggestive of the intimate correlation, in the progressive evolutionary stages of the nervous centers employed in psychical activity and of those concerned in muscular movement. The data in the evolution of the human hand will chiefly be used as the material for illustration.

The intimate relationships existing between higher intelligence and the more highly developed accessory motility of the

[1] Bull: Soc. Anthrop., 1869, p. 301.

human hand has been so striking that it has been noted even so far back as Anaxagoras. The extreme theory has been put forth by many modern writers that human intelligence, as such, has arisen in direct consequence of man's assuming the upright position. The fore limbs, thus relieved of the duties of locomotion which in lower animals is more or less their exclusive function, have found vent for their energy in manifold new employments, and thus introduced the human race to varied world of richer experiences. Intelligence has been the product.

Trace the evolution of the higher human intelligence as we will,—from toolmaking and tool-using to modern invention, from manual signmaking to speech, from hut building to architecture, from picture-writing to painting, from bizarre fashioning of fetiches to sculpture, from rude drumming to higher instrumental music—the development of hand and mentality have ever been in the closest intimacy of association. Under the simple psychological law that processes occurring simultaneously tend to fuse, we have reason to expect, in advance of evidence, that the accessory hand movements and accessory mental powers of man should be singularly related.

There is much in psychology that supports the general theory. Dr. Stricker in his *Bewegungsvorstellungen* contends that in every mental act of the imagination there is a tendency to muscular movement which in many persons rises above the threshold of consciousness. In his own case, when he imagines a man walking he feels simultaneously a tendency in his thigh to move his own leg. When he succeeds in suppressing these muscular tendencies he finds himself unable to imagine. This phenomenon is in accord with modern psychological views. In order to raise the arm, for example, the motor mechanism is set off by the sensory centers which hold in memory the impressions that were received from the joints, muscles, etc., when on previous occasions the arm was lifted; these sensory impulses arising from the movement of some portion of the body have been termed "kinæsthetic" sensations. Consequently when Dr. Stricker imagines a man walking, these kinæsthetic memories are reawakened, and, perhaps, form essential elements in the imagination of the general act of walking as performed by another person.

Darwin, Duchenne, Pidirit and Mantegazza have studied the significance of the expressive movements, especially of the face and hands, and in general conclude that these are weakened forms of movements that were once directed to some practical end; that is, the kinaesthetic sensations that once set off a purposive action, now reappear by force of association with specific traces of their former subjective states in weakened form,[1] and set the movements *partially* in action; hence the clenching of hands in anger, the contraction in fear, etc. In other words, the physiological states which are paralleled by their concomitant mental states are made up of partial re-excitations of ancestral movements.[1] Theodate Smith[2] conducted a series of experiments on muscular memory in the laboratory and found that the kinaesthetic sensatious of speech movements are essential to memory of words; that the memory of visual forms is greatly assisted by associating with the forms to be remembered certain hand movements and as her experiments show, memory thus prepared is from 10 to 22 per cent. freer from error than memory based upon visual observation alone. In this line of speculation, we find ourselves in the end not far from the conviction that the movements of the hand, by racial predisposition and individual education, have some singular connections with the highest level activities of ideation; that thus, in plausible probability, the nervous reaction associated with certain hand movements in lower levels has become represented, "re-represented" and "re-represented" in successive levels, till quite divorced from its previous associate in muscular action, it becomes the nervous structure used exclusively in ideation.

To be explicit, let us trace speculatively by way of illustration the evolution of the nerve processes concerned in a state of moral courage. Our brute-man ancestors did not think courage—they acted it. The kinaesthetic memories of previous similar acts flowed directly into the motor channels of muscular reaction without the complex association of the higher levels. Since consciousness is a concomitant only of sensory processes and not of motor discharges, according to the psychological view now generally accepted, consciousness was of brief duration because the discharge was immediate. Later, however, a portion of the kinaesthetic energy, instead of being wholly discharged into motor channels to excite muscular movement, forced itself upward into higher levels and gradually formed long circuits of sensory irradiation among the structures which are the concomitants of higher ideation. By this irradiation, consciousness was prolonged and the energy given to muscular action lessened. The individual deliberated longer and acted less. The kinaesthetic impulses that discharged into the motor channels of our ancestors, creating in them deeds of physical courage, discharge, in the more complex nervous system of their civilized posterity, into the higher levels and excite this moral courage of thought, let us

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[1] Compare Lindley, *Am. Jour. Psy.*, Vol. VII, p. 506.
[2] *Am. Jour. Psy.*, Vol. VII, pp. 453-490.

hope. Hamlet failed to act—he philosophized. The human race in its evolution, has been playing the role of the Dane over and over again. The moody Hamlet stands meditating in the focus of civilized consciousness while the old tendencies to action in the lower levels, lurk in the emotional twilight of the margin, tingling our nerves and exciting us with the feelings of our ancestry. Such is the prevalent theory summed up in the phrase, "thought is repressed action."

For suppport of this standpoint, theory would require that distinctly lower grades of intelligence should be accompanied by deficiency in manual motility. The lower primates and the human idiot offer fair tests of this requirement. The ape shows rudimentary degrees of human intelligence, just as he also manifests rudimentary human hand movements. The ape arm is capable of rotation at the shoulder and partially capable of extensions, supination and pronation from the elbow joint, but these powers find only their final perfection in man; some species are able to rotate the forearm almost to the human extent; in common with man many species are able to bring the thumb in opposition to the fingers but compared with that of man the movement is very imperfect. They have nearly all the structural movements of flexion, extension of fingers and even some slight lateral movements.

The feeble minded show marked deficiencies in power of movement and, in general, are wanting in just those movements which specially distinguish the human species from lower animals.

"In the will movements," says Johnson,[1] "the difference between the control of the fundamental and accessory muscles was much more marked in the feeble-minded than in normal children. This was more noticeable, the greater the degree of idiocy. Some who could execute gross movements with regularity and control were wholly deficient in the execution of finer movements." Even those who walked strongly were utterly devoid of grace of movement which is the product of finer control by the higher levels of the nervous system. Mr. Johnson gives a number of tests and observations and concludes: "The foregoing observations and tests are corroborative of Mr. Hancock's conclusion (from normal children) that the fundamental precedes the accessory in development of motor ability. It is important to note that all the spontaneous movements were fundamental. Hardly a single one of them could be considered accessory. They were the swaying of the trunk, the movement of the jaw, swinging of the arm,

[1] *Ped. Sem.*, Vol. III, p. 281.

reeling of the head, and the simplest finger movements." Says Dr. Ireland :[1] "The best and earliest sign of idiocy is the deficiency of the grasp. The hand is flapped or vibrated about instead of being employed to seize or obtain an object. Imbeciles are clumsy in the use of the hands *and it is difficult to teach them any exercise of handicraft requiring method and dexterity*. Even imbeciles are generally very inexpert at such exercises as catching a ball or aiming at anything and *it is difficult to teach them greater dexterity*."

Dr. Seguin thus describes a typical idiotic hand: "The hand of R. is small, the nails short and brittle, fingers as if unfinished, no power, no skill, only automatic movements mainly from the wrist. He could not put his fingers in any given attitude. He could not rotate on command that wrist so nimble when striking or vibrating automatically. He could obey the movements of elevation and abduction, but not always, nor with anything like precision."

Féré has gathered the data not only of structural defects of the idiotic hand but he also goes so far as to insist that degrees of intelligence among normal individuals show traces of a direct relation to their hand motility. He finds that the arm of normal individuals admits of elbow rotation inwardly, 15° to 25°, and outwardly 200° to 225°. In idiots, this power of rotation is comparatively very limited. Goutton has pointed out that in many idiots and cretins the power is entirely absent. It will be remembered in this connection that in monkeys this ability to rotate the forearm outwardly is 140° at maximum. In the matter of ability readily to bring the ball of the thumb and fingers into opposition a large percentage of the feeble-minded are able merely to bring the finger points together in the pincer form of the monkey tribe. Sometimes there is inability to bring the thumb in opposition to the little finger. This failure in many cases is to be accounted for by the weakness of the thumb—a characteristic Simian weakness. The last joint of the fingers and thumb in monkeys and idiots alike, is frequently abnormally short. Féré[2] compares the length of this joint (the last phalange, or phalangette) of imbeciles with that of normal persons engaged in occupations requiring manual dexterity and finds a range of length expressed in percentage of the length of the whole hand as follows: thumb, 13 to 20 per cent.; index, 10 to 15½ per cent.; middle, 10 to 16 per cent.; ring, 9½ to 16 per cent.; little, 8 to 13 per cent. He concludes: "The subjects in whom one finds the phalangette more developed are in general

[1] Blot on the Brain, p. 257.
[2] Rev. Phil., Vol. XLI, p. 622.

those who have given proof not only of manual dexterity of movement but also of mental development above the average, while the individuals who are singular for the shortness of the phalangette are *without exception* imbeciles." The phalangette of the thumb is largely controlled in its most delicate manipulations of precise movements by the long flexor muscle, which is absent, according to Gratiolet, in anthropoid apes. It is in the movements controlled by this muscle, according to Féré, that imbeciles show a conspicuous weakness. He remarks that he has observed that persons employed in mental work maintain without exercise, nevertheless, a high motility of the thumb muscles. The arrest of development of the ring and little fingers is common among degenerates making many movements impossible ; the fingers are short or lack the power of independent flexion or to put themselves in the same plane with the others. The flexion of fingers is always more forcible than extension, and in degenerates this difference is as a rule greatly augmented.

Another series of hand defects of significance is that of the lateral movement of the fingers. This power is partially regulated by the depth of the space between the fingers, a greater depth allowing greater freedom of lateral movements. In the gorilla, for example, the interdigital membrane is large and reaches far up between the fingers, binding their action. Hartman[1] has found this same feature noticeable in many of the lower human races, notably negro. In some species of monkeys the fingers are united. Imbeciles frequently show what seems an atavistic tendency in this direction ; in persons of normal intelligence, says Féré, the thumb for example, can be brought to make an angle of 120° to 130° with the index, but in degenerates it is frequently not more than 45° ; the same ratio holds with the other finger angles. Johnson[2] found by examination a very general difficulty among feeble-minded children to open and close the fingers laterally ; some could open the hand between the index and middle finger but not between others. Some who could open fingers laterally could not open the first finger alone. In attempting these movements false movements were often made ; for instance, swinging of wrist, partly closing hand, or shaking whole forearm. These latter substitutions illustrate the weakness of the control of the higher over the lower centers.

Féré concludes regarding the power of independent finger movements as follows : [3] "The disassociated movements of the

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[1] Les Singes Anthropoids, Bibl. Sci. Internal, p. 80.
[2] *Ped. Sem.*, Vol. III, p. 28.
[3] Rev. Phil., Vol. XLI, p. 624.

fingers present considerable variation. With individuals of higher intellectual endowment they are more developed and are accomplished with less energy and greater rapidity. In the degree that one descends in degenerescence, these movements are less numerous, less rapid and less precise; while with individuals of greater intelligence, the amount of work of the fingers acting successively is greater than the work of the fingers acting conjointly." In another work[1] Féré shows that ability to move fingers separately, or to move one hand without the other, is small among the imbecile class. The normal individual is better able to direct effort and to concentrate energy into specific members acting independently. This tendency of the imbecile class to simultaneous movements suggests atavism since simultaneity is the dominating law of the fundamental movements and succession is the human characteristic of accessory movements. Simultaneous movements of the hand suggests reversion to the conditions when the hand was a fore limb.

As a rule, in school children, those of quick movement of muscles are considered brighter, mentally, than those of slower movement. Of course this condition may represent a variety of causes, but this fact is very readily apparent on the whole. In a study which was made to trace the rate of school progress of some two hundred children, it was found that 52 per cent. of the most rapid pupils possessed strikingly quick control of the movements while only 8 per cent. of this class were slow of movement; on the other hand among the pupils of slow progress 40 per cent. were strikingly halting in their movements, and only 25 per cent. possessed a ready control. Also, in the matter of precision 54 per cent. of the rapid pupils possessed accuracy of writing movements against 11 per cent. who were not; while among the mentally slowest, 59 per cent. lacked accuracy of movement and 22 per cent. of them were not precise.[1]

The facts which have been reviewed bring out clearly the close, and seemingly organic, relationship existing between these nervous structures controlling the movements which constitute man's superiority over lower animals, and those nervous structures which function human mentality. The mentally defective are commonly deficient in the ability to control these accessory movements and show many similarities to Simian traits of structure and movement. Such facts necessarily push us toward the conclusion that defects of mentality, as in power

[1] Epilepsies et Epileptiques.
[2] Burk: Individual Pupils vs. Graded System, Northwest. Monthly, March, 1898.

of movement, are commonly due to the failure of higher levels of the nervous system to become functional — levels which are essential both to a higher class of movements and a higher stage of mentality. It is an interesting corroboration of this view that in the other class of highly specialized accessory movements, speech, idiots show a very common deficiency. Dr. Down from an examination of 200 idiots, 7 to 36 years of age, found 33 mute, 16 semi-mute, 83 with indistinctness, 4 stammering, and 62 with fair speech. It is manifestly incorrect to treat idiots as a single class having a common cause of defect. It is with the congenital class that this inquiry is specially concerned, for under this classification fall those unfortunates that date their defect, in the words of Dr. Down, "from earlier uterine life and in many cases to the germ or sperm cell."[1] The studies upon the finer cortical structures in the brains of congenital idiots, which already have been briefly reviewed in the first pages of this article, show striking deficiencies in number of cells, development of the cells in size and in the association fibres connecting them with other cells. The lower centers in the cord, medulla and pons are much more frequently normal. Kaes, who perhaps has made the most fruitful investigation thus far, voices a growing conclusion that both deficiencies in finer structure and the frequent grosser abnormalities find a common origin in an early embryonic period where an arrest of development has occurred, which has thrown the organism off the track leading to complete human development as it were; thus derailed, the nervous system tends to develop, in some features, toward lower racial forms, dependent upon the period at which the arrest occurred and the structures affected. In this line of speculation, Dr. Down some years ago contributed a classification of congenital idiots according to ethnic types — Negroids, Malays, Indians, Mongols. He asserts that more than 10 per cent. of the congenital feeble-minded children are typical Mongols. "They present characteristics so marked that when members of this type are placed in proximity it is difficult to believe that they are brothers or sisters. In fact their resemblance is infinitely greater than to members of their own family."

The simple educational and psychological significance of the facts of this chapter is that the individual, from conception to senescence, follows the order of development of the race, and that any serious mishaps upon the way causes an arrest of development of his nervous system at some partial level. But the facts, except in these extreme cases of arrest, are far from fatalistic in their inferences. Even among the idiot class, the results of

[1]Wood's Monographs, Vol. X, p. 320.

education upon the principle of developing the more fundamental in order to develop the accessory, have approached the marvellous. Those two classics on the subject by Dr. Seguin, "The Idiotic Hand"[1] and "The Idiotic Eye,"[2] illuminate the principle by practical results that are of the most significant value to general education; truly does the editor of *Archives of Medicine* say in announcing Dr. Seguin's death that "the great physio-psychological conception (illustrated practically by Dr. Seguin) must in time — perhaps a long time — attract the attention of teachers in kindergarten schools and colleges." Dr. Seguin began the education of the idiot by training of the hand movements, and of these he selected for the first lessons those which were most fundamental — grasping, supporting, letting go, throwing, catching and leading up gradually by some admirable teaching tact to the accessory, and correlation of eye and hand in natural exercises that called forth the pupil's interest. Strangely, after two years education on this plan, the general mentality of the boy whom he describes had also improved to a degree that was marvellous even to teachers. The stimulation of the evolutionary levels, in their natural order, through the hand training had strengthened them also for discharge of mental functions.

Evolution of Hand Movements in the Development of the Normal Child.

The topic of the present chapter is a difficult one. We meet a baffling complexity and seeming disorder, upon any logical basis, from the moment of birth. Some of the movements of new-born infants are extremely simple, and a large number seem to be built up by co-ordination of these simple movements. But on the other hand there are strewn throughout infancy and early childhood a number of singular movements, which, at their first appearances are highly complex; they are excited by special stimuli; many of them by irregular modification become adapted to ends for which evidently they were not originally employed. If infants first learned to make all the simple reflexes, and this step performed, then proceeded to combine these elements into new unities, and so on, we would have a logical order to retrace. But there are few evidences either in infancy or in later childhood of such steps from the logically simple to the complex. Preyer has shown that in the case of the eyes, each eye tends to a certain extent to be a law unto itself, that the two do not move in perfect co-ordinated unison until several months have passed; yet the same principle will not apply to the movements of the two arms. This

[1] Archives of Medicine. [2] *Ibid.*

pair of bilateral members tend to move simultaneously, when an adult would use one of them independently.[1] Mrs. Moore's child was eight months before it ever used the two hands simultaneously for different purposes. Such conflicts are inexplicable upon any basis of uniform principle. The evolution theory, however, of course steps forward to explain this anomaly on the ground that in animal ancestry the eyes moved independently of each other, while the arms or the fore limbs, on the contrary, moved by bilateral impulses. The facts of observation make the matter even more complex, for we find in very early infancy many co-ordinated movements of the eye, *under certain conditions*[2] and independent arm movements *under certain conditions.* It may be these can be explained on the biological grounds that certain co-ordinated movements of eyes and independent movements of arms are older or more firmly established than others of the same classes respectively.

Ready-made Complexes. We may begin by illustration of some of these singular complex co-ordinations which Minerva-like appear full-fledged at birth. A striking example of this class is offered by Dr. Robinson[3] in experiments upon the ability of new-born infants to hold themselves suspended by grasping a finger or a bar. If we accept the current theory that the immediate ancestry of man lived in trees as many species of monkeys now do, this movement, though highly complex, involving the combination and co-ordination of several muscles of the arm, wrist, and fingers, is, in an evolutionary sense, fundamental. Dr. Robinson has kept records of experiments upon sixty infants, carried out within an hour after birth in the case of at least one-half of them. The infant subject was allowed to grasp a horizontal bar, or a finger, and left suspended in this way, sustaining its own weight. He says that in every case, with only two exceptions, the child was able to hold on "for at least 10 seconds: in 12 cases with infants under one hour old half a minute passed before the grasp relaxed, and in three or four nearly a minute. When about four days old I found the strength had increased, and that nearly all when tried at this age could sustain their weight for half a minute. At about a fortnight or three weeks after birth, the faculty appeared to have attained its maximum, for several at this period succeeded in hanging for over a minute and one-half, two for just two minutes, and one infant of three weeks of age for two minutes and thirty-five seconds."

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[1] Mrs. W. S. Hall: First 500 days of Child's Life, Child Study Monthly, Dec., 1896.

[2] Mrs. K. C. Moore: Mental Development of a Child, Psy. Rev. Monograph Supp., No. 3.

[3] Darwinism in Nursery, Nineteenth Century, Nov., 1891.

Dr. Robinson remarks that the feat is one which would tax the powers of an adult. Wallace has recorded a similar condition of the infant monkey's grasp; one which had seemed secured a hold upon his beard clung so tightly that Wallace was not able, without help, to free himself. In similar vein Dr. Mumford[1] has made an interesting speculation showing the analogy of certain very early movements of the infant to the paddling movements of water animals. He thinks them survival movements of aquatic life. These movements he points out disappear early in the first year, or are modified to form elements of more complex movements higher in the evolutionary scale. The feat of hanging from a stick or finger by the hands, logically would imply the prior development of the arm, shoulder, wrist and finger movements. But such are not the facts. The child grasps a stick and hangs suspended by his arms, long before he is able to pick up any object, or put his two hands together or lift hand to mouth. Logically, the grasp of the whole hand would follow the grasp by the parts, but observation shows us that a certain kind of complex grasp is one of the earliest movements, developed long before some of the very simplest finger movements. Any logical explanation fails at this point. Evolutionary explanation is plausible, for so far as the positive evidence of observation goes the more fundamental and older racial movements appear before the newer and less fundamental, regardless of the order of complexity, except in so far as the accessory as a rule tends to be more complex than the fundamental.

If the human adult or child, beyond the age of infancy, grasps some object, as a saucer or a cup, so large that he cannot put the fingers around it, the arm will be extended toward the object, thumb uppermost, the palm facing upward. The thumb plays the chief role; the last joint hooks over the rim and presses firmly downward, while the fingers underneath press in an opposite direction. This is not the Simian method. The Simian thumb is not strong nor motile enough for one reason, and in the second place it is not its habitual form of grasp. The thumb in the monkey is comparatively of little use, and, as already stated, some species are lacking in the muscle of its chief control. The fingers are used chiefly as a single hook, and in the most arboreal species[1] the fingers have grown together to form a grasping hook. With them, the hand in grasping is used in just the reverse form. The fingers are uppermost, thumb underneath, the palm downward, and the grasp is accomplished by the fingers pressing downwards

[1] Survival Movements of Human Infancy, Brain, No. 79, 1897.
[1] Buckman: Babies and Monkeys, Nineteenth Century, Nov., 1894.

against the palm. Infants follow the method of monkeys, not of man. Give a baby a saucer, or better a glass of water, and note that the rim is seized by the hand with the palm downward, instead of upward as in the case of an older person, while the thumb plays the role of a useless fifth wheel to a wagon.

By what process is the transition to the adult form of grasp accomplished? Undoubtedly imitation is the final directing cause, but there is a functional difficulty in the retarded development of the infant's thumb. He is born with a monkey thumb and must first obtain a human thumb and be able to use it in perfect opposition. Preyer, Mumford and Mrs. Winfred S. Hall have given detailed descriptions of the development of the thumb. For the first two or three months of life the thumb is really a nuisance to the child and is continually in the way. Generally it is curled inside of the grasp. In the case of Mrs. Hall's child it was not till the 11th week that the thumb was brought outside the hand when the latter was clenched.

On the fifth day, Axel Preyer clasped with his fingers his father's finger and it was not until the 12th week that there was certain evidence that the thumb was reflexly brought into use, and even in the 32d week, the movement was not entirely perfect. Mrs. Moore's child was first observed to use the thumb in opposition during 12th week, but she records that it was not till the end of the first year that this method had become established. In the case of Dr. Mumford's child in the 12th week, the diary records: "Does not use his thumb properly for grasping; when he tries to bring the bottle toward him he tucks the thumb out of the way. For the past fortnight he has begun to grasp with his fingers." In the 16th week there is this record: "Has been using his thumb more and more and now never shuts it inside but always outside." In the 28th week, the last record given, we learn that "Grasping movements are much more perfect but still he does not pick up things between the tip of the thumb and finger. Occasionally he grasps a thing between the last joint of the thumb and finger." Mumford concludes that it is often six months before the development of thumb make the elaborate movements of the human grasp possible. Whiie the thumb of the hand is thus gradually gaining in motility and strength *in a human direction*, the great toe is losing motility and strength, *also in a human direction*. Robinson[1] attests from a number of experiments upon new born infants of an English workhouse, that young infants curl their toes over anything grasp-

[1] British Med. Jour., Dec. 5, 1891.

able. When either the palm of the hand or the sole of the foot is touched, the reflex grasp of the fingers or toes is occasioned. Buckman observes that a baby can move any of its toes independently and can move them one from another so as to make a V between any of them. Preyer records that on the seventh day, his child grasped a thin pencil by his toes exactly as by the hand.[1] As the child grows older this power is lost. It is a movement which in the development of humanity has been lost. Mumford records that in the 28th week the toes of his child had lost almost completely the tendency to grasp.

Several other hand movements could be more or less definitely traced, commencing in the infant with complex reflexes, inexplicable as yet upon any theory except that of evolutionary origin, and developing into human forms by modifications and additions that show no trace of logical arrangement. Among these to which reference might be given are the change from rhythmical sluggish movements of the fingers (which Mumford considers a survival from aquatic habits) to human quickness; development from the hooked form and use of the fingers,[2] to independent movement of finger; the habit of using the index to poke about in investigating crannies or new objects;[3] the method of grasping a ball, etc. These constitute but one class of elements with which the child commences his career. They are not simple in the sense of logic for they are not complexes made up by co-ordination of several simple movements previously possessed; the infants who hang suspended by the grasp do not usually grasp objects which merely touch their fingers; the grasping reflex is only set off by touch in the palm of the hand.[4]

Nor do all these complex but original co-ordinations appear immediately at birth. They are scattered along through infancy and childhood suggestively corresponding to the development by distinct parts observed in the growth of the nervous system. The teasing and bullying instincts of children offer suggestive illustration. Among the commonest movements in these activities may be observed;[5] pursuing, throwing missiles, striking, throwing down, holding down, dancing about conquered victim, laughing, clapping hands, pulling hair, pulling ears, etc. Children's natural games are largely made up of mild forms of these elements, the more malevolent tendencies having been elided. Whence came these movements which children acquire without effort and which they execute

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[1] Senses and Will, p. 245.
[2] Buckman: *Ibid.*
[3] Mumford: *Ibid.*
[4] Mrs. Moore, S. and W. 243.
[5] Burk: *Pedagogical Seminary*, April, 1897.

with such natural grace and precision. They have no utilitarian bearing upon the duties of civilized life. A plausible hypothesis classes them with the grasping reflexes of newborn infants—habits common to the race in its primitive conditions and carried forward in the structure of the lower levels of the nervous system.

These complex movements are ultimate units; they do not conform to the purposes of civilized human conduct and are not explicable nor reducible by any process of logical explanation. Corresponding to them are psychic states of equal complexity which find no explanation in the civilized child's present environment. There is a principle well known in physiology and embryology, that a structure or a movement—useful for a certain purpose in a certain stage of the biological scale, loses this purpose in a higher stage and through modification becomes used for some entirely different purpose. This is what Wundt terms heterogony of purpose. Thus as we have seen the fingers have been used for locomotion, then for seizing, grasping, and finally, in man, their ancient purpose is wholly lost, and an entirely new series of uses has taken its place, though the bony structure has not materially changed. Now what are the applications of this view to many of these strange complexes that appear in early childhood, even to include such seemingly evil forms as those which appear in cruelty, bullying and teasing? May it not be, indeed, that they constitute a level in the evolutionary hierarchy, and though in themselves useless, are nevertheless an essential platform from which the co-ordinations of a higher and useful level are formed? It is plausible that the child needs to live to some extent the life of his ancestors in order actually to develop in his own nervous system the kinæsthetic sensations which by the process of higher evolution may serve as the basis for higher forms of activity in the highest levels? It becomes indeed a question of extreme nicety to determine just the exact moment when sufficient actual experience has fully established the racial tendency and the time for inhibition and radiation of the force into higher cerebral associations should follow. Danger of arrest of development at the lower stage is as important as that the fundamental impressions should not be made. Such a view gives these curious phenomena a natural place in child life, and emphasizes the probability that children's plays and games, as mild vaccination forms, serve as mediations between brutal ancestral tendencies in the nervous system, and the higher levels employed in altruistic modern life, between savage racial action and civilized ideation.

Co-ordination of Simple Movements. One who watches a young infant will notice a number of jerky movements continually occurring in practically all the muscles of the body. Some are merely slight twitchings of fingers and small muscles, and they range in scope to those of flinging hand, forearm, or whole arm about vigorously; the legs are moved in the same way. In the same class we must place the play of features, turnings of the eye and various other awkward movements. In some of these movements Mumford finds a rhythm which he thus de, scribes. "Slow rhythmical movements of flexion and extension of the fingers occur, which instead of possessing the quick-incisive character of voluntary movements partake of the sluggish rhythm so familiar to the visitors to the tanks of an aquarium. They often occur in a series of three at a time during a quarter of a minute; then follows a pause during which there is apparently an accumulation of energy in the nerve cells. Then another series of spontaneous discharges takes place, to be in turn followed by another pause." Preyer has described the whole class of these movements as "impulsive" and labors to show that they are "spontaneous" impulses from the nervous system, occurring without external stimulus but exclusively by organic or nutritive processes. This clear-cut division which excludes all external stimulus probably is to be seriously questioned, but this is immaterial for the present. Notwithstanding the evident fact that these movements possess strength and energy,[1] the new born infant is unable to direct his hand or arm movements. He cannot for some days or even weeks bring his hand to his month. Accidentally, in these movements, the hand frequently is thrown to the mouth and the infant sucks his finger; he is unable to remove the thumb from his mouth and must wait till some adult or lucky accident of movement removes it for him. Without purpose and without manifest external stimulus, the elbow, wrist, and finger joints are continually being flexed. Even months before birth these purposeless movements had commenced. What is the significance? As Flechsig has shown, in earliest infancy, practically the whole cerebral cortex is scarcely connected by mature fibres with the centers of action in the spinal cord, medulla and pons. It is not till well into the first month that these earliest connections are made on the sensory side, and the motor connections by which activity is cerebrally directed donot appear until after the sensory has developed. The child is several months old before all portions of the sensory bundles of fibres which pass from the cord to the cortex show maturity in every part.

These movements are most common in the earliest weeks of infancy, and tend gradually to disappear. The fact that the

[1] The strength, under specific stimuli, is demonstrated by the grasp and the power of bodily suspension.

connections of the lower centers with the cortex are not made till late, leaves us to conclude that these early movements are the products of spinal activity, uncontrolled as yet by the higher levels. They are lowest level movements in their simplicity, unmodified by the inhibitions of later human experience which lie undeveloped in the higher strata of the nervous system. They must represent the movements which are racially the oldest entering as elements into human activity. If lower animal movements do appear in human activity, it is in this period we most safely can look for them in their most undifferentiated form. Later in infancy the first connections with the cortex are established. Then sensory fibres go upward, and later motor fibres go downward from these middle centers, to inhibit and control the lower movements in certain particulars. Associations of cell with cell, center with center, develop to modify and make more precise or offer greater alterations in these modifications. Later, a still higher system of control is superposed upon this. From this point of view, the purposeless movements of infants are more intelligible. They are movements without higher inhibition, movements as yet without halter or rein. The objective evidence bears out this supposition. Gradually, this flopping of arm, rhythmic flexions, and extensions, and nervous twitchings tend to disappear. Just in proportion to the capability of an infant to execute voluntary movements of a given limb or organ, these vagrant movements disappear. The two opposed processes are gradual, and Warner[1] records that at three years microkinesis, as he terms it, is still present. It is questionable that these movements ever do completely disappear, as experiments upon the ataxiagraph show. In form, these purposeless movements may be, as Mumford and others claim, survival movements of past ancestry. As such they are useless and senseless, and if this were their only significance they well might be destroyed. Nevertheless they unquestionably have a far more significant place. Children without them are idiots.[2] The modern will theory certainly gives them a functional place. Before a movement can become voluntary, certain sensations of the muscles, skin, joints, etc., occasioned by this movement, must be recorded in memory. These sensations, in form of memory deposit, become the stimuli by which voluntary action is directed and controlled. By these memory traces, just the exact amount of force, the direction, and the method of precision is measured out, when a given movement comes to be voluntarily employed. Sully gives an apt description of this

[1] Mental Science, April, 1889, p. 36.
[2] Tuke's Dictionary of Psychological Medicine, p. 469.

process in an infant eleven weeks old.[1] "Among the objects that attracted him was his mamma's dress, which had a dark ground with small white flower pattern. His hand accidentally came in contact with one of the folds of her dress lying over the breast. In a dozen times or more he repeated the movement of stretching out his hand, clutching the fold and giving it a good pull. A hasty reasoner might easily suppose that the child had now learned to reach out to an object when only seen. But the sequel showed this was not the case. Four weeks later, the diary observes, the child as yet made no attempt to grasp an object offered to him. The clutching was thus a blind movement. Yet it was doubtless a step in the process of learning to grasp." A simple explanation would be that the kinæsthetic impulses consequent from the first accidental reaching and clutching served as stimuli by which the action was repeated, and so on till fatigue set in.

In the light of this consideration, the importance of these rhythmic movements, be they survivals of aquatic and arboreal life or not, is manifest. If through any disorder, the lower levels are unable to produce them and the infant lies quiet and motionless, these sensations, necessary for willed action, never occur, the physical concomitants of mentality are never stored, and the infant lives to become an idiot. These movements, the flotsam and the jetsam of spinal activity uncontrolled as yet by higher centers, are the ultimate units. If we admit that they are survival movements we have here an illustration of a wide-spread physiological principle, that new uses are grafted upon old structures.

The modifications of the ultimates, whether complex or comparatively simple, with which the infant begins life, proceeds in several directions: (1) the breaking up of old bilateral and simultaneous tendencies, characteristic of central movements; (2) the growth of independent movements of smaller parts that previously only moved in conjunction with larger wholes; (3) the co-ordination of various series to form long and complex sequences as we finally find them illustrated by writing, sewing, piano-playing, etc.; (4) the development of precision and accuracy; and finally (5) the response of different movements to a great variety of different stimuli. These modifications perhaps represent the chief accessory lines of development that distinguish human movements as such. Any attempt to give a concrete review of these movements would of course require a volume. Merely a few typical illustrations will be made. Under head of bilateral tendencies which give way to independent movements, Mrs. Hall[1] reports that during the first

[1]Studies of Childhood, p. 413. [1]*Ibid.*

few months the right hand was always carried to the mouth with the simultaneous movement of the left hand. "Even when putting the thumb to his mouth he used the left hand in this way, and finally held the left hand under the right hand while sucking the right thumb. If the left hand was confined so that he could not use it in this way, it was noticeably harder for him to put the right hand to his mouth, while it always annoyed him, causing him to cry." We must be careful not to confuse the age of a movement with the age of a child. I think it is probably true that any new hand movement attempted at any age tends to be bilaterally simultaneous. For example, children of any age, in learning to play the piano are able only after considerable practice, to make movements independently with each hand. Few adults, without practice, will be able to move the left hand in a circle to the left while the right is making a similar circle to the right. Hancock experimented upon 142 children asking them to pat the top of the head with one hand while they made a circular motion about the breast with the other. Forty-five failed entirely, while the others were more or less successful after a time. Bilateral movement is older than independent movement of the hands; the former doubtless is the order of the lower levels; it is overcome by control from the higher accessory centers.

The formation of a successive series from parts previously existing may be illustrated by the following type described by Mrs. Hall. The age of the child was 13 months. "After watching two children play ball he was allowed to join the game. The ball was rolled to him, he picked it up, then leaning far forward placed it upon the floor, but could not push it away. His hand was repeatedly given an impulse which sent the ball forward but even then he could not roll it alone. The ball was thrown to him and he tried to return it, but after raising his arm and reaching the hand forward he could not propel the ball. Again he was assisted in making the requisite motion and when the ball left his hand he screamed with delight. After playing fifteen or twenty minutes, he raised the arm as if to throw the ball, then opened his hand and let it drop out but was unable to give it the forward impulse. The game was played daily and each time at the beginning of the play he experienced the old difficulty; but each day he succeeded after fewer trials than were necessary on the previous occasion, and finally learned to throw the ball in an awkward way. By the 58th week he had become able to throw it in the general direction of his effort, and by the 60th week to throw it with ease and with considerable accuracy."

In this description the difficulties of nervous co-ordination are clearly outlined. The child had already mastered all the movements taken separately, but while these nerve centers could act separately, their co-ordination, not only in a general order of discharge, but in order of delicate nicety of time, was impossible. The forearm must be extended at just the exact moment and the ball released at another precise moment. When we consider the infinite complexity of the whole process our wonder is that it is so quickly acquired. The suggestion leads to the query whether or not movements of similar complexity, but entirely new in racial experience, are learned as readily in later life. I hardly believe they are. Throwing is almost an exclusively human movement though some monkeys have been known to possess it. In strictly human experience, however, it is old and firmly established. May it not be possible that the explanation for the comparative ease with which the child learns this movement be accounted for on the theory that in learning he is retracing paths in his nervous system, more or less distinctly established by ancestral experience? An adult required to perform a movement of similar complexity but entirely new in human experience would not learn as readily and rapidly as the child of thirteen months. Some such supposition is necessary to account for such facts of which this illustration is but a type.

A more complex type of co-ordination, though it represents a much earlier period of life, is illustrated by the following comical instance.[1] "In the 17th week the breast was shown to him while he still held his thumb in his mouth, and then for the first time he seemed to realize that the two were separate and he must release the thumb before obtaining the breast. Up to this time the thumb had been removed for him, but on this occasion no assistance was given him until he himself had made an effort and had failed. He looked at the breast, then worked at the thumb, then cried, but could not take it from his mouth. He was therefore assisted and given the breast. Each time he nursed he was required to make the effort to remove the thumb, and was afterwards given such help as was necessary. Late the next day, after a long trial and some crying, he succeeded in his efforts, whereupon he made a little sound of satisfaction and seized the breast. Six days later he was able to remove the thumb at will and with ease." Leaving out the writer's interpolaton of mental motives, which, perhaps, are not essential, we might, perhaps, express the physical conditions something as follows: In the form of accident, so to speak, the nervous apparatus is matured sufficiently to place the hand to the mouth and also to remove it; further, there is established already a co-ordination between

[1] Mrs. Hall: *Ibid.*

the centers of smell or of sight, so that when stimulated suitably, they excite the movements necessary to take the breast; but the presence of the ungovernable thumb prevents. We clearly have here the separate parts of a somewhat complex co-ordination, but co-ordination is wanting. We know certainly that at this age, four months, some paths to and from the central convolutions of the cortex are matured, especially on the sensory side. Of all sensations that would first develop, on account of their early use, we must conclude that those concerned directly and indirectly with sucking would be conveyed there. Of all kinaesthetic sensations of arm and hand movements which also would be likely to be the earliest to develop in the middle cortical level, those of movement of the hand to and from the mouth would be first, for these are the earliest acquired movements. For six days this hand is specifically trained in removing itself, in close association with sensation from olfactory, visual and hunger centers that are clamorously importuning that something be done, and that something be done quickly. An accident in the path of predisposition solves the difficulty for the first time. Each repetition of it makes the transit easier. The co-ordination is established and it is established in just the same way that racial infancy has established it. Gradually higher centers are developed receiving impulses from the lower, co-ordinating them anew and discharging inhibitive motor impulses, substituting or adding other movements. These, at a still later period, are made the basis for a similar superposition. The earliest progress of a child in movements is in the realm of what is racially fixed and determined. Only with the maturing of the highest centers, factors of extreme plasticity, choice, freedom from racial predisposition are introduced.

This brings us to a point of view of the highest pedagogical significance, to wit, that in the development of co-ordination from lowest to highest, the power of evolutionary habit decreases, and the possibility for special modification increases; that there is a progress in teachableness, or at least the term, education, must be taken in two different senses. In the lower strata of development, where the steps have been worn by racial experience, education that is most serviceable will be that which takes its cue from the racial stimuli and concerns itself with leading co-ordination to take these fixed steps as truly as possible. But later, as the higher strata are reached, when the movement emerges from this deep worn gorge that ancestry has trodden and comes to the point where racial paths are divergent and indistinct, the definition of education changes. Education has now a wider sweep of vision, and instead of following paths, may sight distant goals and lead more directly to it. In a different terminology we might call this early education which is restricted to aiding the child to follow in the steps of his ancestors "fundamental," and that which finds its place later, that which comes in when racial paths grow shallow and divergent, and originality more possible, we might call "accessory" education. Taking wider range in this thought, we may consider the child as the sum of his movements. We must remember, nevertheless, the principle of development by parts, by which some parts reach maturity at later periods than others so that we can never say, in an exact sense, that the child is now in the "fundamental" period of education and then in the "accessory." But in a crude, inexact way, it is certainly true that more lines of accessory education are possible in adolescence than in childhood, more in childhood than in infancy. Using the word "teachable" in the accessory sense, we may say that the child is far more teachable than the infant. Dr. Harris has said that education must be governed chiefly by the needs of objective environment. This assertion is too universal. It is education defined only in the accessory sense. A teacher with only this view plays the part of the bull in a china shop in dealing with those mechanisms of fundamental education which would require us merely to follow racial traces.

There is a familiar dispute in pedagogy whether or not the child should be always allowed to follow his inclinations. One party maintains the extreme position that we should follow blindly the child's interest. Another party stands aghast at the proposal. From this present standpoint taken must we not first discover whether a specific tendency in question is "fundamental" or "accessory?" If deeply fundamental, we must follow nature. If the tendency is one in its accessory period of development, we may perhaps allow objective factors largely to determine.

The child traverses before he is six or seven years old, not only the long deep worn road of racial ancestry, reaching back perhaps as far as arboreal or even aquatic life, but I think we may say, he takes a few paces in certain few co-ordinations that are his own, blazes a few trees and leaves his mark. As we shall later see, by six years of age, he shows evidences in many lines of being far upon the highway of distinctively human capabilities of movement. His fingers and hand that once tended to act only upon the lower simultaneous principle, now can move in fair degree by the principles of independence, and of succession. In the delicate steadiness of central movements and the complex co-ordinations requiring delicate peripheral movements, he has probably acquired half of the ability he ever will acquire. His nervous system has made a prodigous growth—far outstripping any other system. The co-ordinations which have made this possible are the products of this growth.

DEVELOPMENT OF HAND MOVEMENTS DURING SCHOOL AGES.

The present chapter will undertake to review briefly the few studies which have been made upon children of school ages by psycho-physical methods, to determine the rapidity, accuracy, strength and maturity, and fluctuating periods in the development of hand movements. The data, incidentally, however, is suggestive for many other pedagogical problems.

Rapidity of Movement. Dr. W. L. Bryan,[1] in Worcester, and Dr. Gilbert at Yale[2] and Iowa,[3] have experimented upon the degree of rapidity with which children of different ages were able to tap an electric key which automatically recorded results. Dr. Bryan thus tested four sets of arm muscles—shoulder, elbow, wrist and metacarpo-phalangeal finger-joints. In order to secure the free separation of these sets of muscles, the arm of the subject was clamped by means of certain devices to allow movement only of the specific set of muscles. The test in all cases was the greatest possible number of taps the subject could execute in five seconds.[4] The number of children (public schools of Worcester) used in the results here referred to is 729. They ranged in age from 5 to 16 years.

The following tables for boys and girls give the arithmetical mean of the tests (right arm) of all boys, and of all girls of a given age.

TABLE A.—*Boys.*

Age	5	6	7	8	9	10	11	12	13	14	15	16
No.	14	26	35	33	43	37	36	33	34	41	32	26
Finger	19.6	19.5	21.0	23.1	24.4	55.2	27.0	29.3	28.7	31.5	31.6	33.9
Wrist	20.1	23.0	23.7	26.3	27.8	28.5	30.3	31.6	32.3	33.0	34.2	35.9
Elbow	22.7	23.5	24.2	26.1	28.2	28.1	29.3	29.9	31.0	32.7	31.5	32.7
Shoulder	18.4	19.8	20.5	22.3	24.1	22.6	24.1	25.0	25.5	27.2	26.3	28.7

Girls.

Age	6	7	8	9	10	11	12	13	14	15	16
No.	28	32	33	43	37	36	33	34	41	32	26
Finger	19.8	20.7	22.2	24.0	25.8	27.1	28.2	30.3	29.5	29.1	31.3
Wrist	21.6	23.1	24.3	25.5	28.5	30.4	31.6	33.2	30.3	30.9	33.3
Elbow	22.7	23.2	24.4	25.4	27.5	28.6	29.4	30.5	28.8	29.3	30.1
Shoulder	19.9	20.2	21.9	22.7	22.6	24.9	25.7	27.5	26.6	26.0	27.9

[1] Development of Voluntary Motor Ability, *Am. Jour. Psy.*, Nov. 1892.

[2] Studies from Yale Psy. Lab., Vol. I.

[3] Univ. of Iowa Studies in Psy., Vol. I.

[4] The mechanism and conditions are so complex in detail that the reader must be referred to the original article for them.

Dr. Gilbert has made two studies upon rapidity of tapping, one upon New Haven children and one upon Iowa children. In his tests the elbow was held free from the table and the arm was in no way clamped. The subject tapped with the finger but the movement must be interpreted largely as that of a wrist movement. The number of children was approximately 50 for each sex and each age, from 6 to 17 years of age. The number of taps in five seconds for both sexes is shown by the following table:

TABLE B.

Age	6	7	8	9	10	11	12	13	14	15	16	17	18	19
New Haven Boys	21.0	22.8	24.9	25.8	27.7	29.7	30.3	29.8	31.2	31.3	33.0	35.0		
Iowa Boys . . .	22.1	23.3	25.8	27.1	28.3	28.1	30.1	31.1	32.4	34.0	34.0	34.4	36.0	36.7
New Haven Girls	19.7	21.2	23.9	25.0	26.9	27.8	29.6	28.1	28.0	29.8	31.8	31.5		
Iowa Girls . .	22.3	24.2	26.0	26.7	26.2	28.0	29.3	29.5	29.4	31.3	32.2	33.8	34.3	35.3

Without holding Drs. Bryan and Gilbert responsible for the form of all conclusions, we may draw from their studies the following inferences:

I. The rapidity of motor ability of the hand and arm, as indicated by tapping, increases, on the whole, with age and does not reach maturity until the adolescent period.

The results of both Dr. Bryan's and Dr. Gilbert's studies agree in demonstrating this fact conclusively. The rate, though subject to several fluctuations, very significantly increases from six years through the pubescent period. The immaturity of this movement at the age of entering school is shown by the following table of percentages, assuming the rate of tapping at 16 years as 100 per cent.

TABLE C.

	Per cent. of 16-yr. ability possessed at 6 years of age.		Per cent. of 16-yr. ability acquired between 6 and 16 years.	
	Boys.	Girls.	Boys.	Girls.
(Bryan.)				
Finger	57	63	43	37
Wrist	64	65	36	35
Elbow	72	75	28	25
Shoulder . . .	69	71	31	29
(Gilbert . .				
Hand (N. H.) .	64	62	36	38
Hand (Iowa) .	65	69	35	31

None of Dr. Bryan's tests are directly comparable with Dr. Gilbert's, since the subjects in latter held the arm entirely free, and their movement, therefore, is probably a combination of all four of the movements studied by Dr. Bryan.

This fact of the comparative immaturity of children's motor ability excites the pedagogical inquiry whether or not in the existing school requirements, stick laying, needle work, pencil work, etc., of the kindergarten (children under 6 years), and in the writing and drawing of primary children there is intelligent realization that the child's ability, so far as rapidity of movement is a symbol of maturity, is only 60 to 70 per cent. of what it is at 16 years.

II. Girls mature earlier than boys in rapidity of hand and arm movements. This is manifest by a glance at the tables. As shown in Table C, the girls in all but one test (New Haven) have, at 6 years, reached a larger percentage of their 16-year ability than the boys. At 13 years girls have reached practical maturity, and the rate in some of the tests actually decreases after that age. Bryan's girls at 13 years have acquired 97 per cent in the finger test, 99 per cent. in the wrist test, 101 per cent. in the elbow test, and 98.2 per cent. in the shoulder test. In general, therefore, we may say, girls reach practical maturity in rapidity of arm and hand movements at 13 years, while boys increase very materially their ability after 15 years of age.

III. The rate of improvement in rapidity is not regular from year to year, but proceeds by very marked fluctuations, or rhythmical vibrations. Sometimes the rate is very rapid, and again slow, even in some years showing a decrease from the rate of the previous year. Both Bryan's and Gilbert's tables agree in showing four periods of acceleration and four periods of retardation in rate between the years 6 and 17, though there is slight divergence for specific years. The years of highest rate for boys are as follows:

Worcester,	8th and 9th,	11th,	14th,	16th.
New Haven,	8th,	10th and 11th,	14th,	16th.
Iowa,	8th,	12th,	14th and 15th,	18th.

The years of lowest rate are as follows:

Worcester,	10th,	13th,	15th.
New Haven,	9th,	13th,	15th.
Iowa,	11th,	13th,	16th.

Rapidity of movements of hand and arm, in tapping, tends to be greatest when the rate of growth in height and weight is least, and *vice versa*.

This relationship is shown by comparison of the annual rate of growth in height, weight, as given by Dr. Gilbert, and, in the case of Worcester children, by measurements and weighings taken by Dr. G. M. West. In making the conclusion we need not necessarily presume upon any organic relation between rapidity and the growth rate, but it is probable that the processes of rapid anabolism in the addition of new tissues, at least interferes with the dexterity of movement. In Bryan's data the 10th and 15th years, which are the lowest in tapping ability, are the highest in growth rate. In the New Haven study the years of retarded tapping ability are the 9th, 13th 15th and 17th; while the years of accelerated growth rate are the 9th, 11th, 13th and 15th.

V. The more central (fundamental) movements tend to mature earlier than the less central (less fundamental) movements.

Dr. Bryan's tests, which deal with the movements of shoulder, and elbow, wrist and finger, separately, offer evidence upon this point, though perhaps strictly speaking, no one of these movements, except that of the finger, can be considered exclusively accessory or fundamental. In table D this relative immaturity of the finger movement is clearly shown. At 6 years, the finger has acquired, in both girls and boys, a distinctly smaller percentage of its ability at 16 years of age, than any of the others, and the wrist movement is less developed than elbow and shoulder. It has been shown that growth in power proceeds by rhythms and it becomes interesting to know in quantitative form the relative amounts of development that are added within each of these rhythms of advancing age. Table D is constructed with a view of showing this. Each retardation with its succeeding acceleration is considered a period; there are thus in the case of boys four periods: 6 to 9, 9 to 12, 12 to 14, 14 to 16; in the case of girls three periods: 6 to 10, 10 to 13, 13 to 16. The tapping ability at 16 years is taken as 100 per cent., and the figures in the columns indicate the percentage of this 16-year ability added in each of these respective rhythms:

TABLE D.

Boys' Right Arm.

Age	Up to 6 years.	6–9	9–12	12–14	14–16	Total at 16.
Finger . . .	58	14	14	7	7	100
Wrist	64	13	11	4	8	100
Elbow . . .	72	14	5	9	0	100
Shoulder . .	69	15	7	4	5	100

Girls' Right Arm.

Age	Up to 6 years.	6–10	10–13	13–16	Total at 16.
Finger . . .	63	20	14	3	100
Wrist	65	21	14	0	100
Elbow . . .	75	15	10	0	100
Shoulder . .	71	10	18	1	100

These tables show: (1) that in both boys and girls alike, the elbow and shoulder movements have reached a larger per cent. of their mature power than the finger and wrist movements; of the two classes the finger is doubtless more of an accessory movement and of later evolutionary development; (2) that the finger movement acquires a large per cent. of its ability after nine or ten years of age— 28 % in the boys and 17.5 % in the girls. Dr. Bryan, by a different series of calculations, reaches the same conclusions and says: "These results show that the shoulder grows most slowly and the elbow slightly faster, the wrist and finger very much more rapidly." A table stating the number of taps, the elbow, wrist and finger exceeds that of the shoulder, at each age, shows that while this surplus in the case of the elbow is only slight throughout the period from 6 to 16; in the case of the wrist, this surplus doubles and increases from six to sixteen fold. The wrist and finger do not gain materially upon the shoulder until the 11th year and then the finger rates, relatively, spring forward at a greatly accelerated rate. The explanation suggests itself that the shoulder as a central movement has passed the period of extreme nascency very early, the elbow follows, the wrist makes its gains still later and the period of nascency for the finger is certainly not till after 10 years of age and probably does not reach its real culmination in power until sixteen years. Such nascencies have important significance in the management of manual school work.

Development of Strength. Peron early in this century showed by experiments with the dynamometer that Malays and the natives of New Holland are distinctly inferior, in strength of the hand and arm, to French marines. That the civilized races are distinctly superior in hand and arm strength to the lower races of man has many times since been confirmed by Manouvrier[1] and others. M. Féré goes further and contends that among individuals of the same race, the more intelligent have the greater strength of hand. He says[2] that the same dynamometer test, taken upon individuals belonging to different classes of society, have shown that the pressure produced by the effort of flexing the fingers is less with workmen whose profession is exclusively manual than with those whose work requires less muscular force, but whose intelligence comes more into play; and further, that the muscular power is still greater with those of the liberal profession of the same age. The close intimacy of mentality and hand force is demonstrated by M. Féré's well known

[1] Rev. Philos., 1884, Vol. I, p. 645.
[2] Rev. Philos., Vol. XLI, p. 623.

dynamometric experiments[1] showing that the power is very significantly affected by emotional and intellectual states. A subject whose dynamometric force is normally 50-55, shows a decrease to 45 when affected by a disagreeable odor, while an agreeable one causes an increase to 65. In another subject the odor of musk raises the force from a normal 23 to 46. Music and colors produce similar varying effects and various intellectual states show no less pronounced influences. Féré formulates the law from his dynamometric tests that the energy of momentary effort is in proportion to the habitual intellectual functions.

The few statistical studies which have been attempted upon the development of strength during the growing years of childhood and adolescence have been made by Dr. Porter upon St. Louis children,[2] Dr. Gilbert upon Iowa[3] children, and Mr. Roberts in England.[4] The following table gives the absolute annual increments of strength obtained by subtracting the test of one year from that of the next. Dr. Porter's test was made by means of the dynamometer, an instrument which registered mainly the hand-grip power, which, as we have seen, involves one of the most fundamental movements appearing in the first hours of life. Dr. Gilbert's wrist lift involves the hand and fingers, but the principal strain is upon the wrist. The arm

TABLE E.

AGE.	PORTER. Hand-squeeze. Annual increase in kg.		GILBERT. Wrist-lift. Annual increase in kg.		ROBERTS. Arm-lift. Annual increase in lbs.		GILBERT. Arm-lift. Annual increase in kg.	
	B.	G.	B.	G.	B	G.	B.	G.
6½ to 7½ . .	1.6	1.4	1.7	1.0			8.4	6.8
7½ " 8½ . .	1.7	1.6	0.8	1.0			9.5	4.1
8½ " 9½ . .	2.0	1.1	1.1	0.0		1.0	7.2	6.5
9½ " 10½ . .	1.5	1.2	1.7	1.5		0.1	9.6	-1.3
10½ " 11½ . .	1.5	1.4	0.5	0.5		2.3	9.5	7.7
11½ " 12½ . .	2.3	1.7	1.7	0.1	1.0	1.2	7.7	6.3
12½ " 13½ . .	2.4	2.7	1.0	1.9	5.7	3.5	8.6	11.3
13½ " 14½ . .	3.2	1.9	1.1	0.6	2.8	3.2	12.8	6.4
14½ " 15½ . .	4.4	2.0	4.6	1.2	6.0	4.1	23.0	5.4
15½ " 16½ . .	4.4	1.8	3.3	.6	9.6	2.2	8.3	-3.2
16½ " 17½ . .		0.1	3.3	.4	6.4	2.1	20.0	2.8
17½ " 18½ . .			0.0	1.2	2.2	5.0	13.6	1.4
18½ " 19½ . .			1.7	0.0	1.5	1.9	0.0	3.8

[1] Sensation et Mouvement.

[2] Growth of St. Louis Children, Trans. Acad. Sch., St. Louis, March, 1893.

[3] *Ibid.*

[4] Report of Parliamentary Commission on Secondary Education, Vol. V, p. 363.

lifts of Roberts and Dr. Gilbert test fingers, wrist, elbow, and shoulder. They are therefore not safely comparable one with the other. I have arranged them, however, in parallel columns to show whatever parallelism there may be in additions of strength taken in a general sense.

It is clear from this table that strength varies from year to year in rhythms as we have observed in all other tests. The chief accelerations begin in boys from 13 to 14, and continue probably almost until 18 years. In girls the period of acceleration begins a year or so earlier, and, as a rule, begins to decline from 15 to 16; there seems to be a new acceleration after 18 years. From 6 to 10 or 11 years occur periods of gradual increase with very marked fluctuations. In order to determine the relative proportions of increase that occur in different periods I have calculated the following tables. The strength at 16 years has been taken as a base or 100 per cent. By subtraction the other columns are obtained.

TABLE F.

	Per cent. of 16-yr. strength acquired by 6 yrs.	Per cent of 16-yr. strength acquired by 11 yrs.	Per cent of 16-yr. strength acquired between 6 and 11 yrs.	Per cent of 16-yr. strength acquired between 11 and 16 yrs.
Boys.				
Squeeze (Porter)	20	46	27	54
Wrist (Gilbert)	21	46	26	54
Arm (Gilbert)	24	64	22	44
Arm (Roberts)				36
Girls.				
Squeeze (Porter)	23	54	31	46
Wrist (Gilbert)	32	65	32	36
Arm (Gilbert)	32	67	23	45

From these calculations it would appear that in the case of boys only about a fifth of their 16-year-old strength is acquired before 6 years, a quarter from 6 to 11, and over one-half from 11 to 16, during the pubertal changes; in the case of the test upon the whole arm maturity is somewhat in advance. In the case of girls a greater share is acquired before 6 years, their strength acquirement is more rapid than with boys from 6 to 11 years, although the largest increment is added also during the pubertal flux.

These tests shed little light upon the question of the order of fundamental and accessory, since each of the tests largely involves fundamental movements exclusively. But in so far as the lift of the entire arm may perhaps be more exclusively fundamental than the combined movements of the wrist and hand alone, we see from the table that the arm movement seem to mature earlier than the wrist and hand.

Mr. L. W. Kline, in a statistical study of truant children,[1] finds that these children are significantly less developed, physically, on the average, than children of the public schools. He has kindly given me the data of dynamometer tests which he made, but did not use in his publication. These tests were made upon boys from 9 to 14, inclusive, in the Massachusetts truant schools. He also made identical tests upon a number of children attending the public schools of Worcester. While the number of children tested is not as large as desirable, nevertheless, a distinct cleavage is shown between the two classes, and goes to support the other evidences which indicate that hand strength, as well as motility, is in direct relation with the degree of mental development, or what is probably the same thing, strength depends to some extent upon the nerve centres of the higher levels. The following table compares the strengths of the truants and normal children:

TABLE G.

	Truants.		Normal.	
Age.	No.	Mean Strength.	No.	Mean Strength.
9	19	23	69	26
10	20	25	83	30
11	30	30	102	38
12	31	36	121	40
13	47	40	102	46
14	23	51	90	53

Dr. Gilbert, in Iowa, segregated the "bright," "average" and "slow" children, according to their teacher's judgment. While in some tests, *e. g.*, rapidity of tapping, there was shown a distinct line of cleavage in favor of the bright children, yet in the tests of wrist and arm lift no cleavage is shown. Unfortunately, however, Dr. Gilbert combined the figures for both boys and girls in this comparison.

There is a fact of probable significance that the rate of increase in strength is high throughout the pubertal period, especially during the year in which the pubertal sexual changes chiefly occur, 14 to 15 in girls, and probably 15 to 16 in boys. In other tests there is generally a retardation during this particular period, the chief acceleration in height and weight occur before and after. The peculiarity is of significance in connection with a theory that has many supporters, that the seminal fluid has a direct effect upon strength. The relation is one which has been recognized from the time of the Greeks, who practically observed it in the training of their sol-

[1] *Pedagogical Seminary*, Jan., 1898.

diers and athletes. Bierent[1] has developed this law, and the facts these tables express are in agreement with his conclusions.

The literature of strength — increases after seventeen years, with which we shall not deal — is very voluminous. The investigations which have been made indicate conclusively that growth in this direction is by no means at maturity at the age mentioned. The English Anthropometric Committee concludes that the increase is rapid, and then more slowly until 30 years, after which it tends to decline with an increasing rate.[2] He finds a parallelism between the increases of weight and strength.

Precision of Hand Movements. Superficial investigation shows that the nervous mechanism involved in the attempts to be precise with the finger, require first an adjustment of a larger area of muscular and nervous tissues than those of any other movement of the body probably. Precision in drawing a fine line accurately, for example, requires steadiness not only of the finger movement itself, but of the hand, the whole arm, and even of the body. If we observe a child learning to write we find that he holds his breath, and in many cases his legs will be found bracing his body in intense strain. The central muscles of the arm and trunk are called into activity to give support of steadiness as a necessary condition for the fine adjustment to follow.[3] We may, therefore, perhaps consider precision as involving two processes: (1) that of steadiness of the central organization as a platform upon which rests (2) the finer nervous adjustments of the most complex nervous elements.

1. *Central Steadiness.* This phase of the problem has been subjected to investigation by Hancock[4] in the effort of children to stand still. The subject was asked to stand with feet close together and hands at side, to keep his attention on a distant object, and to try to remain still for a minute. By means of the ataxiagraph attached to a cap worn on the head the bodily swayings of the subject are automatically registered upon smoked paper.[5] The test was made upon 168 boys and girls of Worcester, 5 to 7 years of age. His tests show that during these two years the girls gained in steadiness 32 or 33 per cent.

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[1] La Puberté.

[2] Report of Anthropometric Committee, p. 37.

[3] Compare Mercier: Nervous System and Mind, pp. 94-97. Also Féré, Rev. Philos., Dec., 1897.

[4] Preliminary Study of Motor Ability, *Ped. Sem.*, Oct., 1894.

[5] The swaying in adults has been similarly tested by Bullard and Brackett, Boston Medical and Surgical Journal, Vol. I, p. 136, and Vol. II, p. 136; also Huisdale, Am. Medical Journal, Vol. XCIII, pp. 478-485

of the power of control at five years; and the boys gained about 15 or 16 per cent. We may say, therefore, as the indication of Professor Hancock's study, that power of central control increases with age (very rapidly at the ages 5 to 7), and more rapidly in girls than in boys.

Mr. H. S. Curtis in a study of inhibition tested the ability of children of various ages in their ability to sit absolutely still. He concludes: "The ordinary child cannot sit still voluntarily. Children under five years do not on the average sit still more than 30 seconds and children from 5 to 10 years not more than one minute and one-half. Mr. Curtis explains this condition on practically the same ground offered in the paper, viz., that the higher centers of voluntary control are not developed in any degree of maturity until a late period of child life. He finds that mental occupation materially assists in the control of muscular restlessness and that these higher centers of brain action are not developed until a comparatively late period.

Johnson experimented upon feeble-minded children,[1] 7 boys and 5 girls, averaging 13 years, by the same method that Hancock used. He found the average swaying slightly greater at this age than Hancock found among the normal children of five years. The former were of a high grade intelligence for their class.

(2) *Peripheral Unsteadiness.* Corresponding to these larger swayings of the central movements, there are numerous small vibrations in the peripheral muscles involved in the adjustment for fine movements. Though these movements are imperceptible to ordinary observation, they are always experimentally demonstrable. In early infancy these movements are more noticeable in the form of apparently nervous twitchings that constantly occur in nearly every muscle of the body, even during sleep. As has been stated, these are perfectly normal and are signs of health; they tend to disappear in conditions of lowered nutrition, and in idiot infants they are very much fewer or wholly absent.[2] As the infant grows older, they gradually grow fewer and less noticeable. The fact that they gradually tend to disappear may be explained on the ground that as the nervous and muscular mechanism is perfected, the lower mechanisms pass under control of higher brain levels.

Dr. E. H. Lindley[3] has made a study of the automatisms of early childhood and he shows the persistence of many of these earlier simpler forms into childhood and even into adolescence. Though in later childhood many of these simpler

[1] *Ped. Sem.*, Vol. III, p. 282.
[2] Hack Tuke's Dictionary of Psychological Medicine, p. 569.
[3] *Am. Jour. of Psychology*, July, 1896.

movements are combined to form rather complex automatisms, as Dr. Lindley illustrates, nevertheless a large number remain below the threshold of ordinary observation, indicating a more or less incomplete co-ordination of motor discharge or storing of sensory impulses. Such co-ordinations clearly must interfere, as they are greater or less, with perfection of precision in fine finger movements requiring absolute steadiness. Dr. Lindley found that automatisms increase very perceptibly with fatigue, that they are most frequent in accessory muscles and, in general, decrease with age.

Professor Hancock[1] made an experimental test to determine quantitatively the unsteadiness of the shoulder, arm and hand, by means of the tremograph. He tested by this means 25 adult men, 62 boys and 34 girls from 5 to 7 years. The ability of the boys of 5 years was from one-tenth to one-fifth of that of the adults, and the ability of control improved about 50 per cent. from 5 to 7 years in the case of the boys and less for the girls. The girls possessed a much more mature control than boys of the same age.

(3) *Sensory Factors in Precision.* What has been said of these swaying tendencies of central and peripheral movements offers us evidence of the interfering factors which enter the problem of precision. A second series of conditioning factors in obtaining precision, lies in the sensory development. A movement is determined, the modern view of voluntary movement holds, by the sensory kinæsthetic impressions which are stored up in memory. A movement is made, at first accidentally we may say, and the sensory impressions from skin, joints, etc., which in consequence are stored in memory, are used in future discharges of motor impulses. Precision will depend upon their number and the accuracy of habitual adjustment between them and motor discharges. Clearly, as experimented facts show, exercise (*i. e.*, the frequency with which they are impressed upon the memory) will go far to determine motor precision.

The effects of exercise upon sensibility of skin is brought out clearly by Féré.[2] A subject more or less regularly practiced flexing his fingers singly, moving them in laterally and bringing them separately into opposition with the thumb. Sensibility before and after the experiment was tested by Block's instrument for finding the least pressure of a millimeter square that gives sensation. This test applied to the fleshy part of the thumb and finger tops showed that, on the right hand the thumb had gained 32 per cent. in sensation; the

[1] *Ibid.*
[2] Rev. Philos., Dec., 1897.

index, 15 per cent.; the middle finger, 10 per cent.; the ring finger, 13 per cent.; and the little finger, 6 per cent.; on the left hand, the thumb gained 37 per cent.; the index, 11; the middle, 7; ring, 5; and little finger, 8 per cent.

The development in accuracy of these kinæsthetic sensations with increasing age, has been neatly demonstrated by Dr. Gilbert in his Iowa study.[1] The subject was seated before a table upon which were two points 50.8 inches apart; a pencil in his hand was placed at one end of the line. After carefully noting the distance, his eyes were blindfolded, and he was asked to move the pencil along the board and place it as near as possible upon the other point. Five trials were allowed each subject. Averages of these estimates from 50 subjects of each sex and for each age from 6 to 19, are as follows (the figures give in centimeters the averages for each age of the estimate of the distance, really 50.8 cm.):

AGE,	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Boys,	10.7	31.2	38.1	44.4	46.5	46.7	44.7	46.7	46.5	50.3	51.5	53.1	54.9	57.1
Girls,	12.7	20.3	29.7	31.8	38.9	46.5	41.1	43.2	48.3	46.7	51.1	51.0	52.1	51.5

The progressive development with age is clearly shown.

(4) *Growth in Precision.* Dr. Bryan,[2] with a somewhat elaborate mechanism, tested precision of finger movement as it occurs in executing the motions of writing. He used in the test some 600 or 700 boys and girls ranging in age from 6 to 16. He states in conclusion that, "the most obvious fact which appears is the great gain which is made between 6 and 8. Almost one-half the gain in precision made from 6 to 16, in both 'up' and 'down' writing movements, is acquired between 6 and 8 years. A second test to which Dr. Bryan subjected the same children was that of their ability, with a stylus, to strike a fixed point. An electrical apparatus recorded the approximations of error. The boys' right hand from 6 to 16 years gains in ability 60%; the boys' left hand, 55%; the girls' right hand, 56%; the girls' left hand, 58%. The pubertal period seriously interferes with the growth in maturity and the chief gain is before puberty.

Professor Hancock[3] tested some 160 children, 5 to 7 years, in threading a needle, sitting still, holding arm horizontally, attempting to suppress twitching movements, tapping with the fingers in various orders, tying strings, etc. Mr. Hancock draws from them the following conclusions: (1) Children early learn to make movements involving large movements. They succeed easily in large movements of some degree of

[1] *Ibid.*
[2] *Ibid.*
[3] *Ibid.*

complexity. The order of development of control is, evidently, body, shoulder, arm, forearm and hand. In hand control the index finger differentiates before that of the others. (2) Fine and complicated movements are made with difficulty. (3) Children in normal healthy growth show a lack of co-ordination and control paralleled only by ataxic, choreic, and paralytic patients.

A test having a similar significance was used by Dr. Gilbert in his study of New Haven children. The subjects were given 10 weights, varying from 82 grammes to 100 grammes by steps of 2 grammes each, but indistinguishable in size. They were given the smallest weight as a standard, and asked to sort out the others which seemed to be of the same weight. The number of pupils tested was 50 for each year of age and sex, from 6 to 17. Dr. Gilbert thus summarizes: "The results show a gradual increase in ability to discriminate from the ages 6 to 13. After 13 there is a gradual falling off of 6.8 grammes (in discriminative precision), and then another gain till 17. Boys and girls, considered together, gradually increase in ability, but when they are considered separately, marked differences of sex appeared."

In the study, previously quoted, bearing upon characteristics of children who made "rapid," "normal" or "slow" progress in school grades under a system of promotion giving freedom to individuality, it is shown that 54 per cent. of the rapid pupils, 39 per cent. of the normal pupils, and 22 per cent. of the slow pupils are strikingly careful and accurate in their writing and drawing exercises; while on the other hand, 11 per cent. of the most rapid, 34 per cent. of the normal, and 59 per cent. of the slow pupils are strikingly careless and inaccurate. From the evidence of this study we must link accuracy on the whole with a maturer mental development as indicated by school progress.

We may sum up the matter of accuracy: (1) that as a primary condition which makes accuracy of hand and arm possible, the child must have a matured degree of control under direction of his higher level centers (*i. e.*, voluntary). The fact that this maturity is not reached, normally, until the ninth or tenth year, renders questionable the efforts of the school to compel accuracy such as is required by the kindergarten, and also by the primary school, in writing, weaving, etc. (2) That the ability to be accurate in hand and finger movements increases very materially during school ages; (3) that accuracy depends indirectly upon the development of the body as a whole, the steadiness of the trunk muscles being as essential as the accuracy of hand or finger movements themselves; (4) that for purposes of delicate peripheral movements, as shown by ataxographic experiments, etc., the child has not a matured power of control until well into the school period, and long after severe school requirements of accuracy are demanded; (5) that the evidence goes to show that the sensory kinæsthetic sensations, essential in psychological theory, for definite voluntary movements are, in general, in a very immature state until eight to ten years; (6) that while the early years of school life are doubtless the period of nascency for finger and hand movements, nevertheless there is evident need of a clear realization of these physiological conditions on the part of teachers, not only intelligently to direct the training of these movements, but also to guard against unhygienic requirements; (7) that there are manifest dependent relations between general mental ability and power of accuracy of hand movements; (8) that steadiness of the trunk or central movements (fundamental) necessarily precedes ability to be accurate in peripheral (or accessory) movements.

In conclusion, some of the more general suggestions of this review may be restated briefly as follows: 1. The brain grows in its finer structures until a late period in life. There has been a failure to substantiate connection of differences in mentality with the differences in gross anatomy of the brain-shape of skull, weight of brain, form of convolutions, etc.

2. The order of development of the independent parts of the physical and nervous system is, as a general principle (subject doubtless to minor exceptions) from that which is oldest in racial history towards that which is most recent; that those portions which are oldest are most fixed, determined, and least capable of modification by present environment, and those which are relatively most recent are most plastic and subject to modification by education and environment. Among the important pedagogical inferences which follow from this principle, the following might be mentioned:

1. That, taking the activities independently, there is an early period in the development of each part or process, when the purpose of education must be to follow the fixed innate hereditary line of tendency, and to allow the racial instincts fullest play of development (fundamental education).

2. That there follows a later period, in an activity's development, when it passes partially out of the fixed control of racial habit, and becomes more plastic to present environment (accessory education).

3. That the order of logical connection of subject matter belongs, educationally, to the period of approximate maturity of an activity's development, and must not be introduced in

the earlier instinctive period, in conflict with strong evolutionary tendencies.

4. In an extremely loose sense, clearly recognizing the principle that the organism develops by parts, each of which has a different time of beginning its development, a different rate of ripening, and a different period of reaching maturity, nevertheless we may regard the period of infancy as one of predominating nascencies of the oldest fundamental activities largely in control of the lowest level of the nervous system ; the period of childhood from two years to puberty as the period of predominating nascencies of the special sense and their association one with the other : the period of adolescence as the period of predominating nascencies of the highest form of associations, *i. e.*, those which have been developed in the history of the human race.

5. The child's hand at the age of commencing school is relatively immature in power of rapidity of movement, strength and precision. Roughly it would seem that at the age of six the child has acquired only about 20 to 75 per cent. of the power at 16 years of age. It is clear that the period from 6 to 10 years is one of extreme nascency.

6. Deficiencies in the structure of the hand and in freedom of its movements are significantly frequent as accompaniments of deficiency in intelligence. The human hand in early childhood needs opportunity for the fullest possible development which in general proceeds from fundamental to accessory movements. This statement is consequently far from justifying many of the systems now employed in the schools which ignore the principle.[1]

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[1] The educational writings of Dr. E. N. Hartwell, particularly his report as Director of Physical Training in Boston schools for 1894, are of especial value on this problem. References to his articles will be found in Mr. Louis N. Wilson's Bibliography of Child Study, 1898.

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