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By-Anderson, Charles C.

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Nonverbal creativity, here primarily referring to scientific or mathematical creativity, is considered a function of a set of psychophysiological characteristics. The most important of these, necessary and sufficient for nonverbal creativity, is seen to be a slight dominance of hippocampal or cortical inhibitory activity over reticular, or cortical arousal, activity. Considerable evidence, historical, biographical, and experimental, is brought to support this position. To the extent that the verbal centers in the dominant cerebral hemisphere are highly developed in early childhood, the corresponding interpretive centers in the nondominant hemisphere are undeveloped. These two physiological relationships have observable psychological counterparts in the taciturn, noncommunicative person demonstrating nondistractable concentration and susceptibility to mental fatigue and temporary memory impairment, all characteristics of the nonverbally creative person as illustrated historically. (BP)

A THEORY OF NONVERBAL CREATIVITY

by
Charles C. Anderson
University of Alberta
Alberta, Canada

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A THEORY OF NONVERBAL CREATIVITY*

Originality is usually defined as some measure of the statistical uncommonness of responses, while creativity refers to a high professional estimate of the worth of these responses (Maltzman, 1960). Anderson (1966, p. 291) has pointed out that, in terms of certain attributes, a marked discrimination may very well appear between the performance of those high in predominantly verbal measures of originality and those judged to be creative in more nonverbal pursuits such as, perhaps, mathematics and the physical and biological sciences. Indeed on attributes such as "being impulsive", "being talkative", and "using wide categories to process information", the differences are sufficiently serious (Cattell, 1963, p. 121) to warrant the provision of a tentative theory encompassing the characteristic features of nonverbal creativity which is independent of that devised by Anderson (1966) for verbal originality. Before this can be proceeded with, an assumption must be made concerning Toulmin's (in Crombie, 1963, p. 109) distinction between the characteristics of the individual discoverer and the social conditions associated with discovery in general. It is assumed that the function of these conditions, apparently so varied (Needham, 1963, p. 169; Land, 1964) is to remove the penalties attendant upon heterodox ideas and thereby allow any potentially creative individual to entertain the possibility, in Toulmin's phrase, of "...rejecting authority, and establishing the superiority of a modified system of ideas" (in Crombie, 1963, p. 170). This is the point of the Royal Society's motto "nullius in verba" and of Sprat's (in Cope and Jones, 1959, p. 329) emphasis on its educational significance.

A Psychological Approach

Poincaré (1909) provided an early account of mathematical discovery in terms of the "sensible intuition" (1958 (1907) p. 20) of novel and effective combinations, which appear suddenly after a period of intense concentration on a problem (1909, p. 452, p. 453). Poincaré claims that this is a product of "la machine inconsciente" (ibid.,p. 453)[2] which helps to dislodge items of information from their fixed and habitual settings and so set them in motion that "their mutual impact may produce new combinations" (ibid., p. 457)[3]. Support for this approach, which is applicable to the creative performance of Kelvin (Thompson, 1910, p. 430) and Maxwell (Campbell and Garnett, 1889, p. 430) who lived long before the term "unconscious" came into general intellectual use, comes from Binstein (1933, p. 12), Wiener (1953, p. 40) and Selye (1964, pp. 62-66).

A first approximation to a more scientific description of what is, admittedly, still an "inferable unconscious" is Watson's "unverbalized". Watson (1928, p. 97) notes that we learn to respond to a word as we formerly responded to the object with which it was associated and he proposes that the word "unconscious" be applied to "...that part of the individual's object world which he constantly manipulates with his hands, feet and body, but does not name or attach a word to..." (1928, p. 98). Binet (1911) had said this much earlier: "...l'inconscient est la conservation et l'isolement de la partie motrice contenue dans tout processus mental; plus brièvement encore, l'inconscient est une habitude motrice" (1911, p. 42).

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*CCRE is pleased to bring you this paper. The ideas expressed are those of the author.

Documentation of this equation of the subconscious with nonverbalization comes from considering striking characteristics of nonverbal creators; their comparative taciturnity and loneliness (Einstein, 1933, p. 10), their preference for imagery as a medium for processing information (Koestler, 1964, pp. 169-177) and their distaste for words (Hadamard, 1954, p. 75) which are slower than their speedy, subconscious and nonverbal equivalents (Kubie, 1958, p. 31) and are so encrusted with conventional meanings as to be inimical to intellectual discovery. Freud (1946) reports that when in 1886, he presented in Vienna Charcot's theory of hysterical phenomena, referring especially to their frequent occurrence in men, an old surgeon exclaimed to him: "But, my dear sir, how can you talk such nonsense? Hysteron....means the uterus. So how can a man be hysterical?" (1946, p. 25) Presumably the initital representation of concepts is of a visual or kinesthetic and gestural sort (Furth, 1965, p. 198). For example, Schilder (1942, pp. 353-354) claims that concepts in physics like mass, energy and force are based on tactile and muscular sensations such as touching, pushing and pulling, and Piaget (1960, pp. 32-33) puts mathematical concepts in this category. Maxwell (190890 (1870)) mentions a sort of individual who represents laws "...in the kinesthetic terms of childhood" (1890, p. 220), Kelvin being an obvious example (Thompson, 1910, p. 653, p. 830, pp. 1135-1137).

The most important source of this unverbalized material, according to Watson (1928, p. 100), is the situation in which individuals have learned to be silent either because their parents are taciturn or because they frown on children's verbalizing. The resulting taciturnity on the part of the child, if the theorizing of Dollard and Miller (1950) is correct, could give a continuing existence to temper tantrums, fears, rages, and dependencies, all of which are established before the second year of life. These will have a residual autonomic resonance leading to nameless interoceptive and proprioceptive experiences of which the subject is unaware (Razran, 1961, p. 97). Certainly irritability, even hostility, are reactions disproportionately characteristic of unidentified creative groups (McClelland, 1963, p. 1965) and creative individuals like Newton (More, 1934, p. 97), Faraday (Crowther, 1936, p. 73), Pasteur (Vallery-Radot, 1922, p. 325) and even the otherwise saintly Maxwell (Campbell and Garnett, 1882, p. 430).

While this representation of the content of the unconscious is consonant with the imaginal and nonverbal sort of creativity presently being considered, what of unconscious activity, "le travail inconscient"? Piaget's (1962 (1951)) work is relevant here partly because he (Piaget, 1965, pp. 34-35) considered that the operational mode of thinking had to appear, largely as a result of the manipulation of objects before its verbal communication was possible, and partly because he contends that symbolism of the Freudian type reflects "...tendencies and feelings manyof which the child is not clearly aware, for the simple reason that he never questions them" (1962, p. 175). For Piaget, unconscious activity refers to the assimilation of input into schemata without their corresponding accommodation to empirical reality: "...all assimilation which does not combine with accommodation to form an equilibrium...takes place unconsciously... Even in the case of new, creative generalization the origins of the new relationships which appear eludes the subject" (1962, p. 208).[4] Kelvin (Thompson, 1910, p. 444) and Maxwell (Whittaker, 1951, p. 246) exhibited this behavior which is perhaps best exemplified in Appell's (1925) account of Poincaré.

While walking in the Rue du Ruisseau which runs alongside an unprotected stream, crossed here and there by little bridges, he forgot to cross at the same time as his mother and sister; he continued on his way along the other bank, but as soon as he became aware of them, he rejoined them in a straight line, plunging into the water up to his waist (1925, p. 39).

Combinatorial activity, stressed by Poincaré as a necessary and sufficient condition of discovery, may well be a "sleeping partner" in Hertz's (1956 (1899), p. 12) sense of making no contribution to explanation. Saugstad (1955) has shown that problems can be solved with knowledge only of the functional characteristics of their elements and without any need to introduce the combinatorial concept, an effective substitute for which might be the subconscious and largely random scanning of possible relationships among the representations of the relevant information (Golovin, 1903, p. 13, Campbell, 1960). The classic description of this behavior, so very obvious in Kepler (Bronowski, 1903, p. 121) and Darwin (1902, p. 101) is by Whewell (1847):

> ...if we could truly analyze the operation of the thoughts of those who make, or who endeavor to make discoveries in science, we should find that many more suppositions pass through their minds than those which are expressed in words; many a possible combination of conceptions is formed and soon rejected...trans of hypotheses are called up and pass rapidly in review: and the judgment makes its choice from the varied group (1847, p. 42).

This psychological theorizing, however, is not sufficiently powerful. Firstly, it does not account for other important characteristics of the nonverbal creator like the sensitivity (Dolbear, 1911, p. 481) exhibited by Russell (1967, p. 58, p. 201), the curiosity (Selye, 1964, p. 14) of Faraday (Williams, 1960) and the ubiquitous high energy levels (Galton, 1874). Secondly, the predicted correlates are static, i.e., there is no mechanism for explaining the nonverbal creator's fluctuations in standing along an attribute. For example, his disregard of accommodation to the everyday world presupposes a previous concentration on things very unusual or very obvious (Schuster, 1911, pp. 118-119), which do not draw the attention of others. Mach (1910) noted that "The achievement of the discoverer here consists in his <u>sharpened attention</u>, which detects the uncommon features of an occurrence and their determining conditions from their most evanescent marks..." (1910, p. 270) and, after listing many examples, comments (ibid., p. 271) that many of the events were seen long before they were noticed. The power of discrimination of Kelvin (Thompson, 1910, p. 348), Poincaré (Appell, 1925, p. 90) and Pasteur (Dubos, 1950, p. 371) is well attested. This second objection precludes the necessity of considering seriously claims (Myers, 1962, pp. 32-33; Cattell, 1963, p. 123) that "introversion", defined in terms of introspectiveness -- Anthony's (1956, p. 22) "introversive, assimilative tendency" -- Shyness, irritability, and so forth (Eysenck, 1964, p. 20), is an important correlate of scientific creativity.

<u>A Psychophysiological Theory</u>

Consider the young nonverbal creator's curiosity (Trotter, 1941, pp. 134-135) and low threshold of sensitivity to the stimulus. Both are illustrated in Kelvin's noting that the fundamental note of a cornet was an octave higher than the theoretical fundamental note of an open tube (Thompson, 1910, p. 75). Thompson points out that "...Kelvin's enquiring mind could not rest until he had reconciled the apparent anomaly..." (1910, p. 75). After some efforts, Kelvin satisfied himself by producing on the cornet the real fundamental note of the open tube which, so low as to be almost incapable of production, had been replaced in point of its name and place by the octave above.

Berlyne (1963, p. 290) has shown that the individual is aroused by the "collative" properties of stimuli. This term refers to the fact that these stimuli force the individual to make comparisons; he compares one component of the stimulus with another (complexity) or the entire stimulus variable with expectations based on past experience (surprisingness) or the comparison is between simultaneously-aroused expectations (uncertainty) and so forth. Berlyne (ibid., pp. 293-294) attributes the common arousal-inducing effect of the collative variables to "conceptual conflict" or the simultaneous instigation of incompatible symbolic responses. The relationship, acknowledged by Berlyne (1966, p. 84) between "conceptual conflict" and Piaget's "disequilibrium" can be derived from the fact that they represent a mismatch (Berlyne, 1960, p. 303).

The curiosity exhibited by nonverbal creators is taken to be Berlyne's epistemic curiosity leading to epistemic behavior. The former refers to a questioning which implies the existence of a conceptual conflict related to dissatisfaction with current answers to problems, and the latter refers to the gathering of information in order to reduce this dissatisfaction (1963, p. 324). Maxwell's early life was full of questioning (Campbell and Garnett, 1882, p. 28). The young Faraday was drawn into reading and eventual experimentation after meeting a "theoretical void" (Williams, 1960, p. 520) and Wiener (1953) reports that "...unresolved ideas were a positive torture to me until I had finally written them down and got them out of my system". (1953, p. 212)

There is a curious paradox here. The power of collative variables to induce arousal is attributed by Berlyne (1960, p. 181) to the unleashing by the discrepant cues of a "reticular barrage" (Moruzzi, 1963, p. 290) which bombards the momentarily upset cortex and necessitates an adaptive response. His conclusion that uncertainty is "...one of the burdens that the human frame is least equipped to stand" (1960, p. 206) could very well be generalized to all collative variables. Nevertheless, the nonverbal creator lands in this state by avoiding certainty and refusing to accept unsatisfying standard interpretations and existing formulations which are exploited by the conventional problem solver (Kuhn, 1964, p. 36) because they provide some measure of conceptual clarification (ibid., p. 56), an obvious example being Lavoisier's replacement of phlogiston with oxygen as the active ingredient in combustion and as the common factor in all acids.

Any attempt to explain this preference for uncertainty by resorting to Berlyne's (1967) recent acceptance of moderate levels of arousal as pleasurable must fail before the fact that the nonverbal creator works himself into states of arousal much in excess of this. Thompson (1910) describes Kelvin's enormous daily activity. "Time was his enemy, with whom he seemed to wage a continual warfare, consulting his watch at intervals, sometimes with great perturbation" (1910, p. 443). Helmholtz, himself a prodigious and incessant worker (Koenigsberger, 1906, p. 305), reported to his wife that Kelvin "...will not stop for meals or any other consideration" (ibid., p. 806). All Eiduson's (1962) creative scientists reported themselves to be happy in their work and yet they went on to mention many almost daily incidents involving stress, anxiety, fears, and so forth. "The men fret and storm, go home preoccupied and irritable. Once the problem breaks, they are faced with the new anxieties that come with the demand for writing it up and getting it into print before they are scooped" (1962, p. 160).

An alternative interpretation is that this paradoxical preference for uncertainty is just what is to be expected from a combination of sensitivity and epistemic behavior in one individual. The epistemicist, having acquired a considerable amount of information, will rapidly become bored unless he moves ahead into further areas of conceptual conflict by which he is easily aroused. For example, Vitz (1966), by correctly predicting that subjects with training and interest in music should prefer a greater amount of variation in sequences of tones than subjects with relatively little musical training, lent some plausibility to the underlying hypothesis that "...with exposure to a stimulus, some of the variation is organized and stored away by S, and the perceived amount of variation in the stimulus declines. To keep the amount of perceived variation at the preferred level, S must seek out a new stimulus with a greater amount of objectively defined stimulus variation" (1966, p. 75).

Sensitivity and epistemicity in combination, then, comprise a vicious circle from which there is little hope of exit. For example, Faraday was no sooner cured by rest from his nervous crisis, brought on by overwork, than he plunged back into work again (Williams, 1965, p. 359), and Kelvin was harrassed by unsolved problems almost to the end of his long life (Thompson, 1910, pp. 884-885). Unavoidably plagued by the conceptual conflict in unsolved problems, these men must aim at what has been noticed before in the case of the criterion for selecting potentially adaptive thought trials, a simple general solution that will solve a number of problems. This goal of simplification, which resembles Pribram's (1964, p. 95) conclusion that the organism is reinforced when information has been ordered, is obvious in Kelvin's being concerned all his life about the possibility of constructing a comprehensive theory of matter (Thompson, 1910, pp. 1014-1015) in which the necessary explanatory concepts were reduced to the smallest number (ibid., pp. 1084-1085). In the same vein, Williams comments that "it was the conviction that forces were inherently identical that inspired Michael Faraday during the major portions of his scientific career" (Williams, 1965, p. 64). Light, magnetism and electricity could be represented as ray vibrations (ibid., p. 388) and Faraday tried to bring gravity into this general account. "Surely this force must be capable of an experimental relationship to Electricity, Magnetism and the other forces, so as to bind it up with them in reciprocal action and equivalent effect", he wrote in his diary of March 19, 1849 (ibid., p. 466).

Why an individual should allow himself to follow his curiosity into such unpleasant experiences of conceptual conflict cannot be answered within the confines of Berlyne's theory, which also contains no representation of the nonverbal creator's high energy levels and correlated powers of retention (Galton, 1874). In connection with the former characteristic, for example, Galton's respondents described themselves in terms of such phrases as "much endurance of fatigue and hard work" (1874, p. 78, p. 79). There are many references to athletic feats calling for great expenditure of energy: "Have rowed myself in a skiff 105 miles in twenty-one hours..." (ibid., p. 81) and "Excelled...in athletic sports, especially in long jumping (18 feet)" (ibid., p. 87). Rutherford (Eve, 1939, p. 397), Maxwell (Campbell and Garnett, 1882, p. 152, pp. 200-205, pp. 294,295) and Kelvin (Thompson, 1910, p. 595) were outstanding exemplars of these traits.

Reciprocally, fatigue plagues nonverbal creators, touching the normally indefatiguable Kelvin occasionally (Thompson, 1910, p. 414). Faraday's breakdown (Crowther, 1935, p. 117; Williams, 1965, pp. 358-359), beginning with overwork, involved the following symptons: headaches and a feeling of tiredness, loss of memory, feelings of discomfort in the presence of strangers, and impairment of motor skills evident in dizziness and inability to write properly. All of these symptoms reappeared in Faraday's last years (Williams, 1965, pp. 496-499) and his personal note explaining his retirement includes the phrase "...loss of memory and physical endurance of the brain (MacDonald, 1964, p. 49). Newton (More, 1934, p. 381) had a similar nervous crisis, also brought on by overwork and characterized by fatigue, sleeplessness (ibid., p. 234) and an absence of consistency in thought (ibid., p. 382), at the same age as Faraday. Maxwell also had bouts of this forgetfulness and dizziness from overwork (Campbell and Garnett, 1882, p. 176). This relates to the impairment of some central co-ordinating mechanism such as is described by Penfield and Roberts (1959, p. 20) which has memorial and motor functions.

Penfield (1954, 1965, 1959), in his mapping of the cortex of epileptics by probing it with an electrode, stimulated the speech area in the dominant hemisphere and the correlative area in the nondominant hemisphere. While stimulation of the former area prevented the subject from speaking, stimulation of the latter correlative area released visual and auditory memories to which attention had been paid years before (1965, p. 791), and also interpretive or evaluative responses at the conscious level. The latter area, the centrencephalic or interpretive cortex, the existence of which is not entirely hypothetical (Thompson, 1965, p. 387), has characteristic functions which make it a possible substrate for nonverbal discovery.

In the first place, Penfield (1965, pp. 789-791) speculates developmentally about the functionally "uncommitted" cortex in each hemisphere as compared to the sensory and motor cortices which are "committed" from the start of life. When the child is still an infant, the "...area of temporal cortex that is to be used for speech is interchangeable with that to be used as interpretive cortex" (Penfield and Perot, 1963, p. 691). As the child ages, however, certain areas of the uncommitted cortex are exclusively devoted either to the function of speech or to the function of interpreting experience. An assumption, usually tacit, in all this is that there is a reciprocal relationship between the amount of the left hemisphere used for speech and the amount used for the interpretation of experience. For example, Penfield (1965) reports that, when an adult's major speech center in the dominant hemisphere is damaged, "He can never establish a completely new center on the non-dominant side...because he has, by that time, taken over the initially uncommitted convolutions on the non-dominant side of his brain for other uses" (1965, p. 789).

Accordingly, it may be inferred that, the less speech is indulged in, the larger the area of the cortex devoted to interpretation. Penfield (1965) presents the reciprocal of this in his conclusion that, after the age of 10 or 12 years, the "...general functional connections have been established...for the speech cortex. After that the speech centre cannot be transferred to the cortex of the lesser side... This non-dominant area that might have been used for speech is now fully occupied with the business of perception" (1965, p. 792). This would account for Einstein's linkage of nonverbal creativity with taciturnity and, in view of the fact that young females talk markedly earlier than young males (Watson, 1965, pp. 331-332) and are markedly superior in performance in the elementary school with its emphasis on verbal performance (ibid., p. 541), it would also account for the relatively small number of females who are nonverbal creators (McClelland, 1962, p. 144).

Secondly, the centrencephalic system provides a neuronal record, like a tape recorder or strip of film, on which are registered past events to which an orienting response has been made (Penfield and Roberts, 1959, pp. 53-54), the indispensable memorial basis of nonverbal creativity. Penfield's description of this record resembles the account by Dubos (1950, p. 371) of the observational powers of Pasteur. Again, Penfield (1959, p. 1720) claims that this replay of past experience is accompanied by an interpretation or evaluation of it as the same or different from present experience, and he assumes, therefore, that the system contains a recognition mechanism which allows an individual to become suddenly aware that a stimulus, say a man, has been seen before. "The sight and sound of the man has given you an instant access...to the records of the past in which this man has played some part. The opening of this forgotten file was subconscious. It was not a voluntary act" (1959, p. 1724). The present claim is that this subconscious scanning of past records and selection of relevant experiences for comparison with the present experience (ibid., p. 1725) comprises the process of nonverbal discovery.

Finally, while the anatomical site of the ganglionic record need not necessarily be at the point stimulated by the electrode (Penfield and Roberts, 1959, p. 49), nevertheless Penfield (1961, pp. 57-58) and Magoun (1963, pp. 134-135, p. 137) provide evidence that both sides of the hippocampus are at least important transaction mechanisms (Green, 1964, p. 589) in the preservation of that record. Hippocampal stimulation has two important effects which are necessary conditions for the appearance of nonverbal creativity. Firstly, it activates an "arrest" reaction which resembles the nonverbal creator's occasional loss of "...la conscience du monde vulgaire" (Appell, 1925, p. 90). McLean (1957) records that in the cat, there was a total loss of awareness, "...an inability to respond appropriately to happenings in the environment" (1957, p. 134). Secondly, afferent stimuli from all modalities activate the hippocampal theta rhythm and its behavioral correlate, the presence of the orienting response, and it is generally accepted (Flynn, McLean and Kim, 1961, p. 380; Magoun, 1963, pp. 135-138; Pribram, 1964, pp. 104-105) that hippocampal stimulation, by preventing the individual from being distracted by irrelevant stimuli, makes possible an association between temporally separated events. It is not surprising, therefore, that nonverbal creators dislike distractions and try to have them removed (Eve, 1939, p. 346). Dubos (1950) comments that "Pasteur's meditations could proceed only in silence, and the presence of any visitor foreign to his preoccupations was sufficient to disturb him" (1950, p. 60).

There is one difficulty about implicating the centrencephalic system in nonverbal creativity. Penfield and Roberts (1959, p. 32) report that the experiences carried in the neuronal records are of a visual and auditory sort exclusively. How, then, can the kinesthetic templates at the basis of nonverbal creativity be recorded in the centrencephalic system? Gregory and Wallace (1963) from their case study of a man who recovered his vision, as a result of surgery, after being blind almost from birth, conclude that the results provide evidence "...for transfer from early touch experience to vision many years later" (1963, p. 40). For example, the man could tell the time by looking at a large clock on the wall because he had told the time by active touch before his operation (ibid., p. 13). Furthermore he could recognize any letter in the upper case but not in the lower case because he had learned capital, but not lower case, letters in a blind school (ibid., pp. 16-17). While in his later drawings, done six months after the operation, some lower case lettering does appear, nevertheless he was largely unable to draw anything he did not already know by touch (ibid., p. 31). As Gregory (1966) put it, "...he was able to use his previous touch experience for his newly found vision" (1966, p. 196). Consonant with this is Held's (1965, p. 84) finding that quick adaptation to perceptual distortions is possible if the subject is allowed to make voluntary use of his muscles in the usual way, and with Inhelder and Piaget's (1964) claim that "All knowledge of objects is a function of those action schemata to which the object is assimilated...the subject...perceives objects as things which are modified, or are capable of being modified, by his own actions" (1964, pp. 6-13).

And so nonverbal creators like Newton (More, 1934, p. 7, p. 72, pp. 134-135), Maxwell (Campbell and Garnett, 1882, p. 30 1. 198) and Kelvin (Thompson, 1910, p. 82) made models and were interested in optics and visual perception, and photography is a frequent hobby for creative scientists (McClelland, 1962, p. 151). Presumably the visual template in the neuronal record is the physical basis to which the sensitive epistemicist has inevitable and subconscious recourse in times of conceptual conflict and its associated memorial strain.

A relationship between memory and energy can be found in the work of Hyden (1961, 1964, 1965), who has shown that the presence of ribonucleic acid (RNA) is indispensable to the consolidation of the memory trace. Furthermore, the concentration of RNA in the neurons increases as a result of their stimulation (Hyden, 1965, pp. 199-200), a small fraction of this RNA differing in base chemical composition from the RNA found in the untrained control groups (Hyden, 1964, p. 56), and decreases under fatigue (Gerard, 1963, p. 27). The mechanism regulating this production of RNA is the interlocking of each neuron with its own surrounding glia cells in a system, the reciprocal functioning of which has been shown by Hyden and Lange (1965) who found that, during sleep, enzyme activity, signifying an "increased energy utilization during the production of proteins..." (Hyden,1961, p. 30), is high in the neurons, low in the glia, while during wakefulness this relationship is reversed. Since the neurons and their interlocking glia cells are energetically open system (Hyden,1956, p. 183), a particular function of the glia is to supply the neurons with energy. "The neuron has a great capacity to produce RNA and proteins with increased nervous functions which consume a high level of energy" (Hyden,1961, p. 32). Accordingly, any increase in neural stimulation effected by the sensitive epistemicity of the nonverbal creator will, by increasing the production of RNA, ensure the effective consolidation of the memory trace which is the basis of later creative performance, or the speedy scanning of past records which comprises current creative performance. Accordingly, this performance may well be associated with an enhanced RNA production and corresponding glial activity. Binet in his gloss on Poincaré (1909, p. 453) and Selye (1964, p. 117) report an antecedent of creative performance in sleep, when increased RNA production has been observed (Hyden and Lange , 1965). Russell (1967), for example, describes how to solve some of the problems which appeared during the writing of Principia Mathematica. "Every evening the discussions ended with some difficulty, and every morning I found that the difficulty of the previous evening had resolved itself while I slept" (1967, p. 145).

However, the present use of Hyden's results stops short of a commitment to his (1965, p. 232) conception of a change in RNA as embodying the items to be recorded. Acceptance of Gerard's (1963, pp. 28-29) report that speeding up RNA production in neurons shortens the fixation time during which a memory can be established implies nothing about the mechanism behind this effect. An alternative conception regards the storage of memories in terms of relatively enduring structural changes functionally linked with "...changes at the receptive component of the synaptic mechanism" (Gerard, 1963, p. 27). Roberts (1965, pp. 302-303) speculates that RNA, among other chemicals (ibid., p. 294), influences memorial consolidation by facilitating synaptic connectivities (ibid., p. 299), an event which is associated with "neural excitability" (ibid., p. 294). This resembles

Landauer's (1964, p. 177) speculation that the savings in learning of planaria injected with extract of RNA from trained planaria are due to the possibility that the RNA in the new experimental organisms makes the neurons in that group more sensitive to the CS, and with Walker and Tarte's (1963) finding that high arousal during learning results in a more intensely active trace and superior retention. Biological studies of memory deficit lend a greater precision to these positions.

Barbizet (1963) describes the features of an amnesie de memoration. The patient faces a situation, perceives and construes it, and reacts normally, but he is unable to effect the neuronal changes required to memorize, so that after a few seconds he will not remember what he has just experienced...the patient has forgotten the meal he has just eaten, the visit he has just been paid, the question he has just been asked, the paper he has just read...(1963, p. 127).

This was Faraday's problem in his old age. In a letter of August 19, 1867 printed by Williams (1965, p. 493) he writes: "My memory wearies me greatly in working: for I cannot remember from day to day the conclusions I came to." In an earlier letter of spring 1843 during his first nervous crisis, he writes of one of "...my low, nervous attacks, with memory so treacherous that I cannot remember the beginning of a sentence to the end..." (ibid., pp. 358-359). Deficits of this sort are attributable to impaired functioning of the hippocampal formation; irreversible deficits to bilateral hippocampectomy (Penfield and Milner, 1958, p. 495) and reversible deficits to bilateral stimulation of the hippocampus. In Brazier's (1964) summary: The striking feature of this temporary memory loss was its restriction to the field of recent experience, long-term memory and the ability for immediate recall being unimpaired. Since this effect proved to be completely reversible, it would seem clear that the stimulating current had not broken up the mechanism responsible for the storage of the memory of this period but had temporarily blocked its retrieval (1964, p. 308). Furthermore, Bickford (in Brazier, 1964, pp. 309-310) has found a linear relationship between the duration of the stimulation and the amount of retrograde amnesia or temporal extent of the deficit in memory for events preceding the one that caused the impairment (Milner, 1959, p. 40, p. 52). There is a third source of these memory deficits. Experimental overtraining followed by a variety of hippocampal and temporal neocortical lesions causes little disruption of learning whereas similar lesions in the course of learning lead to serious deficit (Adey, 1964, p. 246).

The nature of the retrieval mechanism can be arrived at by finding the factor, common to overstimulation and the introduction of lesions, which is responsible for the common memorial loss. Penfield and Milner (1958) point out that the "...recording mechanism for the stream of conscious experiences normally preserves that record in the hippocampal area, as that person turns his attention to something else" (1958, pp. 493,494). An essential condition for the preservation of this record is that "...the trace be kept ceaselessly active" (Milner, 1959, p. 51). Perhaps this is carried out by the production of RNA which would be much reduced by lesions and equally by the fatigue consequent upon overstimulation. For example, Bain (1894 (1855)) talks of "...a profuseness of energy, put forth in trials of all kinds on the chance of making lucky hits" (1894, p. 631). In order to account for the results from overtraining and the increasing retrograde amnesia with increasing overstimulation, it might be further presumed that the reactivation and retrieval of memories which are better consolidated will require less energy. This speculation concerning the mechanism relating RNA to memorizing is supported by the fact that, in the matter of the RNA content of brain tissue, the highest content and the greatest RNA turnover is in the grey matter of the cerebral cortex, the hypothalamus and the hippocampus (Gaito, 1963, p. 474). Presumably major organs in the cortex and brain stem must be protected against fatigue. A test of this speculation may be entered here. If all this is the case, and in point of Penfield and Milner's (1958, p. 491) demonstration that there is no evidence of memory loss if the hippocampal zone in only one area is impaired, the other area assuming its work, then it may be predicted that, in such a situation, the production of RNA in the remaining intact hippocampal zone will be markedly increased over what it formerly was when both zones were active.

The condition precipitating the "arrest" reaction remains to be discussed. Since it occurs at a level of energy output somewhere between violent sporting activity and states of fatigue, the linkage of hippocampal activity and the energizing of behavior, illustrated in a patient of Bechterev mentioned by Penfield (1959, p. 1724), must be examined. Grastyan et al., (1966) refer to an organism's movement towards, or away from, an object as "pull" and "push" behavior respectively. In their study of hippocampal electrical manifestations accompanying these behaviors in the cat, they (1966, p. 36) found that hypothalamic stimulation of near-threshold value switched on by the experimenter elicited an orienting reaction accompanied by the hippocampal theta rhythm. Interruption of this stimulation, caused by the cat's depression of a large pedal during locomotion, was accompanied by withdrawal from the pedal (push) and the appearance of hippocampal desynchronization, manifested in the presence of a faster rhythm to the exclusion of the theta (Grastyan et al., 1959, p. 432: Stumpf, 1965, p. 477). Several repetitions of this experimental situation resulted in permanent avoidance of the pedal. Strong stimulation at the same point in the hypothalamus resulted in flight-like running, crouching and withdrawal behavior accompanied by hippocampal desynchronization. When depression of the pedal switched off this stimulation, the animal stayed on the pedal and experienced an "arrest" reaction associated with the reappearance of the theta rhythm (Grastyan et al., 1966, p. 30).

On the assumption of the reciprocal functioning of reticular[6] and hippocampal states as manifested in the reciprocal relationship between measures of reticular and hippocampal arousal (Grastyan et al., 1959, p. 424), these findings can be explained in the following way. When stimuli, which arouse the organism and elicit an orienting reaction become noticeably intense, hippocampal activity is evoked to reduce this level of arousal and inhibit the orienting response. Successful accomplishment of this goal is presumably pleasurable -- Ursin, Ursin and Olds (1966) have shown that hippocampal stimulation has reinforcing properties and Ito (1966, p. 267) has supported a correlation between synchronization and positive reinforcement[7] -- and provides the energy necessary for the organism to sustain further adaptive behavior such as resisting all attempts to bring it into contact with the pleasure-reducing pedal again. A very intense state of arousal initiated by increased stimulation evokes hippocampal activity of a presumably more intense sort which energizes the attempts to escape. Whenever this high level of arousal is reduced by the removal of the stimulation and is suddenly brought under the control of the perseveratingly massive hippocampal activity, the "arrest" reaction appears.

This hypothesis rests on two assumptions. The first is that the cortex, sensitive to the fact that reticular arousal has advanced beyond a tolerable level, triggers hippocampal arousal which exercises the sort of restraining influence on the reticular formation observed by Adey, Segundo and Livingston (1957, p. 15), Grastyan et al, (1959, p. 427), Grastyan et al, (1966, p. 34), McLardy (1959, p. 447) attributes the same intensity-grading function to the hippocampus, presumably a neces. ty in subconscious processing of information. The second assumption is that hippocampal arousal both protects the organism from the "reticular barrage" especially in the form of the continual distraction labelled the orienting reaction (Green, 1964, p. 590), and energizes it in preparation for defensive motor activity (Adey, 1961, p. 585) in the form of resistance or convulsive clutching of the pedal. The neurological records of hippocampal functioning are consistent with the assumptions. The baseline or "resting" index is the theta rhythm, a product of afferent input and its accompanying necessary level of arousal (Stumpf, 1965, p. 483). Stumpf (ibid., p. 482) has noted that as the gradient of reticular simulation increases, a reciprocal relationship can be observed between a slowing down to the point of disappearance of the theta and the appearance, eventually exclusive, of the faster rhythm. With the removal of the stimulation and of the necessity of hippocampal arousal as a defensive measure, the reappearance of the theta alongside, and eventually to the gradual exclusion of, the faster rhythm, is associated with the overt "arrest" reaction which heralds the successful disengagement of the individual from stimulus.

It is hypothesized, therefore, that the occasion of this slight dominance of hippocampal over reticular arousal is a necessary and sufficient condition of nonverbal creativity, provided the assumption is made that the individual involved has a repertoire of appropriate information in the form of a neuronal record which is entered at the point of conceptual difficulty by a relevant stimulus which may be either conscious (Selye, 1964, p. 117) or subconscious. Strong reticular dominance will result in the relative inactivation of the neuronal records and the concentration by the individual upon any available method of reducing arousal, while strong hippocampal dominance will be difficult to initiate and sustain in the absence of the "reticular barrage". Since the nonverbal creator spends his energy freely in his marginally successful control of arousal, he will be plagued by occasional bouts of fatigue, the existence of which he must accept because his sensitive epistemicity forces him ineluctably to solve problems. Accordingly, the criterion or stop-rule of simplicity is employed to halt scanning because he cannot sustain the continuing memorial strain, presumably Bruner, Goodnow and Austin's (1956, p. 86) "cognitive strain", imposed by the necessity of acquiring and retaining large amounts of only partially and variously related information. It is not surprising that such a poorly controlled and concentrating individual should be aroused, as was Newton (More, 1934, pp. 79-80, p. 97) by the irrelevant and stupid remarks of critics, by demands that he pay attention to mundane considerations, Cavendish being the obvious example (Cattell, 1963, p. 121), or by unexpected interruptions, as was the case with Pasteur (Dubos, 1950, p. 60). This is likely to be true even if no consideration is given to the fact that, during the "arrest" reaction, the characteristic muscular intensity can be transformed by an appropriate stimulus into rage behavior (McLean, 1957, p. 134) and to the inverse increase in the threshold of the stimulus required to evoke signs of that behavior when the hippocampus has been ablated (ibid., p. 136). In the human situation, it is also not surprising that such an individual should withdraw from others and be relatively taciturn in their presence.

The current theorizing can account for an otherwise recalcitrant observation, the disproportionate infertility of nonverbal creators. This may be a product of their living at relatively and consistently high levels of arousal with a consequent increase in secretion of adrenal androgens which are known to inhibit reproduction (Christian, Lloyd, and Davis, 1965). An alternative hypothesis is attractively cruder, but less obviously testable. McLean (1957, p. 134) notes that, after hippocampal activity, pleasurable reactions such as the grooming of the genitalia and partial erections are observed. Reciprocally, Masters and Johnson (1965, pp. 295-300) point out that, in every phase of sexual response, there is much muscular tension and voluntary and involuntary movement. Presumably the sexual excitement induced by strong hippocampal activity will be greatly reduced by fatigue. As a result, successful conceptions by any existing wives will be disproportionately decreased, as will interest in marriage by the nonverbal creator.

The adequacy of this theory appears to be difficult to test because of the awkward manipulations involved in establishing a marginal hippocampal control of reticular arousal. However, it should be remembered that the function of the reticular formation in this particular matter is simply to induce and sustain moderate levels of hippocampal activity, and that this can be carried out only if a state of marginal control is arranged. A more direct way, bypassing the reticular formation, of inducing and sustaining hippocampal activity and thereby allowing an easier falsification of the theory involves the use of drugs.

Consider, first, LSD - 25. Chapman <u>et al</u>., (1962, p. 188) report that the ingestion of small amounts of LSD - 25 (25 - 50 micrograms) is associated with the alternating appearance of the theta and its pattern of desynchronization. Ingestion of larger amounts (100 - 300 micrograms) elicits a flood of past memories and a dissociation from environmental reality, both of which are characteristic of nonverbal creativity. Accordingly, the ingestion of LSD, the amount to be determined by investigation, will lead to the evocation, in any individual thoroughly familiar with a problem on which his attention is focussed, of a variety of solutions, one of which will be found to be creative. Secondly, the same effect will be produced in any individual similarly informed who ingests any hypnotic drug, (Uhr and Miller, 1960, p. 87) which causes his attention to be centred on a problem. Another effective drug might be amphetamine. Callaway and Dembo (1957) found that its ingestion elicited a narrowing of the attention which represented "...an increased freedom from peripheral environmental influence" (1957, p. 75) and Eysenck (1965, p. 34) that it evoked "introverted" behavior patterns like vigilance or the tendency of a person "...to keep on attending to a series of weak and widely-spaced stimuli" (Eysenck, 1964, p. 86).

One final reservation has to be made. This theory is held to apply to those individuals whose creative performance generally involves nonverbal symbols. This does not preclude the lively possibility of differences among sub-groups. For example, pure mathematicians cannot be sorted completely with mathematical physicists who, like Newton (More, 1934, p. 134), Maxwell (Campbell and Garnett, 1882, p. 157), and Kelvin (Thompson, 1910, p. 653) find problem solving in mathematics much more fatiguing than in physics because study of the latter discipline "...leaves a more or less presentable trace on the memory..." (Campbell and Garnett, 1882, p. 305). Mathematical training, as Maxwell (1890 (1870)) puts it: involves fatigue... Some of us, on the other hand, may have had some experience of the routine of experimental work. As soon as we can read scales, observe times...this kind of work ceases to require any great mental effort. We may...tire our eyes and weary our backs, but we do not greatly fatigue our minds (1890, p. 247). On this topic, the present theory has nothing to say.

Educational Implications

The child with nonverbal creative potential, possibly even performance, must find it hard to survive without a sense of frustration in almost any kind of educational environment (Russell, 1967, p. 43). This may well be particularly true of the boy. As Roe (1963, p. 133) has pointed out, teaching in the elementary school is heavily verbal with an emphasis on rote learning to the exclusion of nonverbal problem-solving, a situation which, according to Kuhn (1963, p. 35) applies also to the teaching of science in the high school. Such a verbal emphasis will suit the female whose significantly superior elementary school performance (Watson, 1965, p. 396) is matched by an equally superior preschool verbal performance (ibid., pp. 331-332). Furthermore, competence in beginning reading requires the association of symbol and sound in accordance with the direction of the teacher, the kind of performance more likely to be obtained from the obedient and hard working female (Maccoby, 1967, pp. 27-28). The historical antecedent of this is the Royal Society's motto, "Nullius in Verba" and of Sprat's (in Cope and Jones, 1959, p. 329) emphasis on its educational significance.

It may be argued very compellingly that the number of such individuals is too small to warrant a change in the selection and preparation of teachers. However, discovery may be subjective, in the form of a "private illumination" (Sym, 1965) when the individual suddenly becomes aware of a new way of ordering formerly acquired information. He may not be the first to do this -- for example, a report in the New York Times, February 12, 1967, p. 26, disclosed that a young mathematician had rediscovered one of Euler's theorems -- but the sudden discovery represents a new clarification of information <u>for the young student</u>.

How can the existence of such a set of individuals and their psychometric impact be established? The dominant trait of these individuals, a function of their strong hippocampal activity, is their ability to concentrate on issues to the exclusion of irrelevant stimuli. An appropriate instrument, the spheres test, has been devised by Uznadze (1966). It is based on the theory that repeated presentations of the same stimulus establish a set in the subject which is said to be fixated when it causes the learned response to be elicited in a similar situation. The number of presentations of the stimulus before set is fixated and the number of trials needed to extinguish it varies among individuals concomitantly with their sensitivty to conditioning. Uznadze found, as did Eysenck, that impulsive subjects do not condition (fixate set) well because they orient to many different aspects of the environment (Pribram, 1964, pp. 87-88). In this connection, Uznadze describes: ...a completely distinctive group of subjects who in contrast to the other groups, never fall under the influence of the fixing experiments, never fix the set which arise in each individual case, and therefore always gives the correct estimate of the size of the experimental objects. We see that the usual number of fixing exposures is inadequate for the production of a fixed set in these subjects, so that a new set arises as a result of each individual exposure. In this case we are dealing with persons lacking in internal directing power, and apparently entirely under the control of outside impressions, and thus distinguished by their extreme extraversion (p. 49).

The counterpart of this group, the individuals with presumed nonverbal potential, is described by Norakidze (1966), in Berlyne's terms, as "conflictual" and "excitable" and unable to free themselves from a set once it has been induced.

One of my graduate students undertook a study based on the hypotheses that (a) the intellectual performance of elementary (grade 1) children could be described in terms of two dominant and uncorrelated factorial dimensions, a verbal and a nonverbal factor, and (b) that the variables of maleness, taciturnity and ease of conditioning as measured by the set test would show a heavy loading on the nonverbal, but not on the verbal factor.

These predictions are at odds with those stemming from the work of Kagan (1965) and Kagan et al (1964). Kagan (1966a, pp. 620-621) has shown that, in the case of the performances of Grade 4 boys, impulsivity, defined as the making of very fast responses to problems without "...considering the differential validity of alternative answers".. (1966b, p. 583) is correlated significantly with the tendency to make word errors of all kinds in reading. Furthermore this impulsivity is associated with nontaciturnity (Couch and Keniston, 1960, pp. 167-168) and a persistent orientation to the outside world (ibid., p. 167) which will result in a resistance to conditioning. Accordingly, there will tend to be a relationship of reciprocal exclusion between support for the current theory and that for Kagan's position.

Fifty-one grade 1 subjects were tested from a middle-class suburban school in Edmonton. The following tests were administered: the Lee Clark First Reader Reading Test, Form A; three Piagetian tasks of concrete operations (logical addition, logical multiplication based on matrix tests, and logical multiplication based on class intersection); a set test in the haptic modality, a version of Kagan's measure of impulsivity-reflectivity (the MFF test), the WISC, and a taciturnity measure calculated by imposing a normal five-point scale on the teachers' rating of the students in order from the most talkative (1) to the least (5).

The matrix of intercorrelations was subjected to principal axes factor analysis according to Householder's method. Only two factors were eventually extracted and were rotated according to the varimax criterion for simple structure (an oblique Procrustes rotation added nothing to the interpretation). The first factor was defined primarily by scores in reading, being characterized by high loadings on all the reading subtests and on the WISC verbal. The second factor was clearly a nonverbal one, having negligible loadings on the reading and, to a lesser extent, on the WISC verbal. Correspondingly there were significant loadings on the Piagetian tests and the WISC Performance scale. Accordingly, some support was adduced for the first hypothesis. In the case of the second factor, however, negative loadings appeared on the spheres and the taciturnity tests and the size of the loading for the sexual variable (in the direction of maleness) is increased into significance. This finding at once invalidates the current second hypothesis, and supports Kagan's position.

And yet I am reluctant to dismiss the current second hypothesis because of its adequate illustration in occasional case studies. One case in the current study was a boy who was extremely taciturn during the interview, at home and in school. He had a WISC verbal I.Q. of 100, a WISC Performance of 120, and the lowest reading score in the class. He was driving his teacher to distraction because he "can't think". What she meant was that he could not assimilate verbal information to verbal codes, and could not give adequate verbal responses to verbal questions. His scores in the Piagetian tests were above average. He fixated set on the second trial and maintained it for thirteen critical trials, which puts him in the high excitability low extinction group according to Uznadze. By contrast, consider the case of Jacqueline M. She scored perfectly on the reading and additive classification tests, and had a verbal I.Q. of 125. In contrast, her performance I.Q. was 100, her score on the matrix test was only slightly above average and that on the intersect was below average. Although she fixated set on the first trial, she also lost it after only four critical trials, well below the mean. She was rated low in taciturnity (she was rather talkative) and responded very quickly to the MFF. Her teacher considers her an ideal student.

Are these individuals so small in number that their study and possible educational plight can be dismissed on the basis of time-cost considerations? Before this likely possibility takes place, one alternative should be considered. The group tested, apart from being very small, was of superior economic status, a condition associated with nontaciturnity on the part of parents (Kohn, 1963, p. 352). By contrast, parents from lower socioeconomic levels are relatively taciturn. Accordingly, the application of the same battery of tests to individuals from a lower socioeconomic stratum might so change the factor loadings on the correlates as to warrant the existence of a number of nonverbalists sufficiently large to make an educational accommodation to their unusual psychological functioning worthwhile.

FOOTNOTES

1. Much of this work was carried out with the aid of a Canada Council research fellowship.

2. Binet's (1909, p. 453) gloss on this matter points out that Piaget's account contains two hypotheses concerning the origin of mathematical discovery, one involving "unconscious work", the other "cerebral freshness". However, in view of Poincaré's other examples and Kekule's (in Findlay, 1948, p. 42) introspections, "cerebral freshness" is at best only one condition facilitating discovery. A superordinate formulation encompassing both possibilities will be provided later.

3. Relevant here is Veblen's (1954) contention that the Jews contribute disproportionately to creativity because, as "ethnic aliens", they are skeptical of current preconceptions and "conventional verities" (1954, p. 227).

4. The use of Piaget's hypothesis necessarily implies acceptance of Binet's (Reeves, 1965, p. 198) position, which is supported by Lashley (in Beach, 1960, p. 532) that all problem solving is subconscious in its assimilative aspects.

5. This concept refers to "...an arrangement of work capacities, potential or aroused..." (Freeman, 1948, p. 34), the potential energy being stored in the tissues of the organism for use in activity (Duffy, 1962, p. 17). The same physical energy is used for problem solving or for muscular tension and any consequent response (Duffy, 1951, p. 32).

6. Gellhorn (1957, p. 173) has stressed the contribution of the hypothalamus to the reticular formation, the orienting response (Sokolov, 1963, p. 547) being a specific example.

7. Berlyne (1967) on the basis of Grastyan's work, has agreed that a moderate state of excitement is pleasurable and thereby abandoned his (1964) former position that there is a linear relationship between reinforcement and arousal reduction. However, the fact that hippocampal control of arousal is reinforcing raises the lively possibility that reinforcement comprises not arousal-reduction but successful hippocampal activity, in which case Berlyne's relationship may still hold.

(NOTE: A ten-page bibliography was included. This can be provided on request)