The Method of Co-Twin Control
Author(s): Arnold Gesell
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public should understand these things and, understanding, they will have greater confidence in what is being done.

Certain other factors having a bearing on the metal problem should be mentioned:

1. Industry requires more metal during a period of expanding production than after the expansion is completed. The plant stocks must be increased both ahead of and in the production line. Industry has been expanding during the past year or more, and part of the apparent metal shortage has been used to fill these plant "pipe lines."
2. Plant inventories, in raw material, material in process and finished product, are not known. The fear complex should stimulate late rather large inventories, and spot checks tend to confirm this view. In general, capacities and inventories are apt to be underestimated and requirements overestimated.
3. Much equipment, labor and material, such as in the machine-tool industry, are now being extensively used to prepare defense plants for production. When the defense plants are tooled up, these facilities will be liberated, in part, for direct defense production.
4. Plans are under way all along the line to expand the production of the primary metals. The magnitudes range from millions of tons of pig iron and steel, down.

In an effort to appraise all these factors, good and bad, I venture the following opinions:

a. There will be ample metal for the greatest defense production of all time.
b. In addition, there will be ample metal to keep up all the essential services, including food, heat, light, transportation, communication, water and gas.
c. There will be a considerable amount of metal for civilian uses ordinarily regarded as non-essential for defense.
d. The kind of metal available for many civilian uses will in many cases represent impairment, but the impaired products will serve well during the emergency.
e. Many of the substitutions will probably have a long-range effect on many products and processes, and, perhaps, even on habits.

In conclusion, it may be interesting to record impressions gained from many personal contacts during the past six months and covering most phases of the metal industry. In general, the people having the least confidence in our ability to produce are those farthest from the production lines. They are the ones with little information about what is actually going on and little comprehension of what it takes to really produce. On the other hand, the men in the storm-center of production—executives, engineers, scientists, foremen and skilled workmen—have unbounded faith that our defense production will greatly surpass anything the world has ever seen. Assuming that the latter group is the better qualified to pass judgment we are, even now, in great need of unity of purpose and action lest this vast production comes too late.

THE METHOD OF CO-TWIN CONTROL

By Dr. ARNOLD GESELL
YALE UNIVERSITY

GROWTH is an irreversible process. In investigating the growth process one might like to train a child, and then compare him with what he would have been if he had not received the training. This can not be done; there is no way to make the desired comparison. But we may study a pair of identical twins with just such comparisons in mind. We may train one twin (T) experimentally, and reserve the co-twin (C) as a control. C becomes a scientific kind of stand-in-double for T.

In 1927 the writer, in collaboration with Dr. Helen Thompson, undertook a comparative study in which two highly identical twin girls, T and C, were observed from early infancy to determine, first, their developmental correspondence and, secondly, their developmental divergence, as affected by training confined to one twin. A thoroughgoing similarity in physical and behavioral characteristics was amply established by repeated examinations and measurements.[1, 2]

The method of co-twin control had its origin in a stair-climbing and cube-behavior experiment begun when twins T and C were 46 weeks old. Twin T was trained daily in climbing a 5-tread staircase. At 52 weeks she climbed the staircase in 26 seconds. Twin C, at the age of 53 weeks, without any previous training or experience, climbed the same staircase unaided in 45 seconds. As a comparative check, Twin C was then trained for a period of 2 weeks. At the age of 55 weeks she climbed the stairs in 10 seconds. The climbing performance of Twin C at 55 weeks was far superior to that of Twin T at 52 weeks, even though Twin T had been trained 7 weeks earlier and three times longer. At 56 weeks and again at 3 years their performance on the experimental staircase was amazingly alike. These clear-cut quantitative results, sup-

[1] Arnold Gesell, "The Developmental Psychology of Twins." From A Handbook of Child Psychology. Worcester, Mass.: Clark Univ. Press, 1931. Ed. Carl Murchison, pp. 158–203.

[2] Arnold Gesell and Helen Thompson, *Genet. Psychol. Monog.*, 6: 1–124, 1929.

ported by minutely analyzed cinema records, established certain relationships between learning and maturity.

In a similar way for a period of 6 weeks, Twin T was trained and stimulated in exploitive play with ten one-inch red blocks. Every effort was made to perfect and to elaborate her patterns of cube behavior. Twin C again was reserved as an untrained control. Detailed analysis of cinema records showed a remarkable similarity in the cube behavior of the twins at 46, 52, 63 and 79 weeks of age.

In a later study Strayer[3] used the same co-twin control method to determine the relative efficacy of early and deferred vocabulary training. The twins were separated and kept under continuous observation. Twin T was trained from her 84th to 89th week. Twin C was trained for 4 weeks beginning with the 89th week. C reached a higher level of language performance after 28 days than did T after 35 days of training. T was only slightly superior at 93 weeks; three months later the difference was negligible.

When the twins were 4½ years old, Hilgard[4] used the co-twin control method to compare the effects of early and delayed practice in motor and memory performances—ring tossing, walking board skill, digit and object memory and paper cutting. Three months and also six months after practice, the performances of the twins on all tests were as similar to each other as at the beginning of the experiment.

Through an exceptionally fortunate convergence of circumstances it has been possible to follow the development of these self-same twins for 14 years. Numerous observations and coincident comparisons were made at advancing ages. Simultaneous observation with segregation of the twins was accomplished by a duplex non-communicating suite, equipped at the end with a single one-way-vision window. The findings of these studies and of the several co-twin control experiments have been coordinated in a recent monograph which reviews the life careers of the twins for the whole period from early infancy to adolescence.[5] Both physical and behavioral characteristics were considered as follows: (1) *Anthropometry:* height and weight, palm prints, dentition, hair and eye color, hair histology, vision, hearing, health, eating and sleeping, puberty, homeostasis. (2) *Motor Behavior:* postural demeanors, laterality, locomotion, fine coordination. (3) *Adaptive Behavior:* mental growth rates, block construction, play behavior, drawing, school achievement. (4) *Language Behavior:* infant vocalizations, enunciation, vocabulary, conversation. (5) *Personal-Social Behavior:* adjustments to home and school, inter-twin dominance, humor, fantasy, personality traits.

This sequential study represents a biogenetic application of the combined methods of co-twin control and coincident comparison, to determine the stability of behavior resemblances and differences. The long reach of the data, with numerous nodes for cross comparison, made it possible to analyze such factors as ontogenetic timing, physiological tempo, attentional traits and the durability of individualities of behavior and personality. So far as Twins T and C are concerned many of our conclusions seem firmly grounded.

Some of the conclusions may be safely generalized. But the method of co-twin control has its limitations. A twin is not an absolute unit of measurement; and we must start all over again with the next pair of twins. In this sense, twins are uncalibrated and fall outside the calculus of biometrics. Nevertheless, when one reflects that even physics with its beautiful mathematical precisions is never on absolutely absolute ground, we may accord a certain pragmatic value to a method which applies a norm that equals in complexity the phenomena to which the norm is applied.

The distinctive feature of the method of co-twin control is its utilization of an organismic norm. Such a norm has certain advantages over a purely statistical criterion. Statistical norms and devices can never be organismic because they are either heterogeneously unselected or homogeneously selective and must therefore remain analytic and partial in application. But a control co-twin is by definition highly identical with the individual under investigation. He is in fact the sum of a statistically numerous multitude of forces. He is an embodied quantity who with respect to any distinguishable trait is more or less than the investigated individual.

A control co-twin is a synthetic standard of comparison with a highly equivalent prenatal and postnatal life career, except for divergences which are experimentally created or naturalistically observed. When one contemplates the almost infinite number of variables which enter into the shaping of any life career, it must be granted that an "identical" co-twin who brings these variables into finite and manageable range is indeed an extraordinarily powerful statistic in his own integral person. His individuality is unique, but by definition it is almost a replica of the individuality which is being assayed. The patterns of twin and co-twin do not exactly superimpose. But by matching we measure. We expose areas and directions of discrepancy. The almost complete identity of the datum and the measuring device gives augmented significance to all discrepancies which can be defined and accounted for.[6]

[3] L. C. Strayer, *Genet. Psychol. Monog.*, 8: 209–319, 1930.

[4] J. R. Hilgard, *Genet. Psychol. Monog.*, 14: 493–667, 1933.

[5] Arnold Gesell and Helen Thompson, *Genet. Psychol. Monog.*, 24: 3–121, 1941.

[6] Arnold Gesell, SCIENCE, 88: 2280, 225–230, 1938.

With such a rationale it is evident that the method of co-twin control requires that a thorough parity and identity be established by careful measurements *prior* to the period of comparative observation and experiment. If there are any significant antecedent discrepancies they should be recorded and taken into account in subsequent comparisons. H. H. Newman in an interesting chapter on the psychology of twins has called attention to the importance of this aspect of the method of co-twin control. Referring to the New York twins, Johnny and Jimmie, he writes:

> One of these twins, we don't remember which and it doesn't matter, was trained to be a little gentleman and the other allowed to grow up like Topsy. As time went on they became very different in motor skills and in social behavior. This would have been an excellent case for testing the effects of different environment and training on two individuals alike in their heredity, except for one defect in the setup. Johnny and Jimmie turned out to be a pair of two-egg twins! So the co-twin control feature was entirely lacking and therefore the experiment was meaningless. . . .[7]

Newman properly points out that unless one-egg twins are used it is impossible to distinguish hereditary from environmental effects. Galton had the same thought in mind, when in 1875 he wrote his famous paper entitled "The History of Twins as a Criterion of the Relative Powers of Nature and Nurture."[8]

The method of co-twin control presupposes one-egg twins of thoroughgoing similarity, with environmental factors held constant, except for precisely defined or experimentally imposed differentiations.

The method of co-twin control therefore is essentially a clinical method, designed for the intensive study of monozygotic pairs (to say nothing of monozygotic triplets, quads or quints!). It can attain statistical status, in the ordinary sense of that term, only when a sufficiently large number of comparable co-twin control studies are accumulated. Such a statistical extension of the method was advocated in 1930 by Blakeslee and Banker in a paper entitled "Identical Twins as Biological Controls in Educational and Other Human Problems."[9] The authors suggested an endowed school for one-egg twins instructed by monozygotic twin teachers! Just at this time, Russia organized an institute for twin research in connection with the Maxim Gorky Medico-Biological Institute of Moscow. The method of co-twin control was used on a systematic scale for a large variety of studies. A score of scientists pooled their resources and in 1935 some 800 pairs of twins, mostly children, had been investigated. This striking enterprise resulted in significant studies, but was terminated about three years later.[10, 11]

Although these large-scale investigations are impressive, it should be pointed out that the method is not essentially enhanced by multiplication.. A large number of cases may confirm trends and define new problems; but numbers will not in themselves be productive. The method is clinical; it is productive in the single instance. It depends heavily upon the ingenuity and insight of the experimenter; and it is capable of far-reaching adaptations. The areas of possible application have scarcely been scratched. The method has numerous potentialities in the field of medicine, which already boasts a vast literature on twins and twinning phenomena. The medical literature, however, is largely documentary, rather than experimental. Co-twin control has many unrealized applications in clinical physiology, pharmacology and experimental therapeutics.[12]

The method of co-twin control is peculiarly suited to the analytic study of the processes of child development and the genetic factors of life-career. If the instincts of an organism were only tinted pink and the habits robin egg blue, as Lloyd Morgan whimsically wished, then we might better grasp the relationships of nature and nurture, of endowment and environment. This differential stain has not been forthcoming; but with the aid of co-twin control studies we may glimpse the interrelations of learning and growth, the effects of specific training, the influence of attitudes and emotional patterns. The method may be fruitfully used to explore these intricate problems which are so resistant to absolute biometric approach. The method preserves the togetherness of the individual and affords more insight into the total integrated economy of performance and development. Critically used it is to a considerable degree self-corrective.

When so used we come, in the end, to a better understanding not only of one individual but of two, for one reciprocally elucidates the other. When the comparisons are made successively over a long ontogenetic range, this comparative method also illumines the processes of growth. Differences and correspondences in timing establish points to reckon by. And even though the method is one of dead reckoning and lacks the elegance of classic mensuration, it may bring a mariner shrouded in shifting fogs to the vicinity of a port.

[7] H. H. Newman, "Multiple Human Births. Twins, Triplets, Quadruplets and Quintuplets." New York: Doubleday Doran. xi + 214 pp., 1940.

[8] Francis Galton, *Jour. of the Anthropological Institute*, 5: 391–406, 1876.

[9] A. F. Blakeslee and H. J. Banker, *Proceedings of the American Philosophical Society*, Vol. 69, 1930.

[10] S. G. Levit, *Character and Personality*, 3: 188–193, 1935.

[11] A. R. Luria, *ibid.*, 5: 35–47, 1936.

[12] Arnold Gesell (with Eugene Blake), *Archives of Ophthalmology*, 15: 6, 1050–1071, 1936.