Articles

Biological Bases of Childhood Shyness

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The initial behavioral reaction to unfamiliar events is a distinctive source of intraspecific variation in humans and other animals. Two longitudinal studies of 2-year-old children who were extreme in the display of either behavioral restraint or spontaneity in unfamiliar contexts revealed that by 7 years of age a majority of the restrained group were quiet and socially avoidant with unfamiliar children and adults whereas a majority of the more spontaneous children were talkative and interactive. The group differences in peripheral physiological reactions suggest that inherited variation in the threshold of arousal in selected limbic sites may contribute to shyness in childhood and even extreme degrees of social avoidance in adults.

A CHILD'S INITIAL REACTION TO UNFAMILIAR EVENTS, ESPECIALLY other people, is one of the few behavioral qualities that is moderately stable over time and independent of social class and intelligence test scores. About 10 to 15 percent of healthy, 2- and 3-year-old children consistently become quiet, vigilant, and affectively subdued in such contexts for periods lasting from 5 to 30 minutes. An equal proportion is typically spontaneous, as if the distinction between familiar and unfamiliar were of minimal psychological consequence (*1*). Empirical indexes of a pair of related, but not identical, constructs in adults, often called introversion and extroversion, are among the most stable and heritable in contemporary psychology (*2*).

Comparative psychologists and behavioral biologists may be studying an analogous form of variation among members of a species or closely related strains. Mice, rats, cats, dogs, wolves, pigs, cows, monkeys, and even paradise fish differ intraspecifically in their initial tendency to approach or to avoid novelty (*3*). Some investigators have explored the physiological correlates of these behavioral differences. For example, about 15 percent of kittens (*Felis catus*) show prolonged restraint before approaching novel objects and people and, as adults, do not attack rats. These avoidant cats, compared with a larger complementary group that does not retreat from novelty, show greater neural activity in the basomedial amygdala following exposure to a rat, as well as larger evoked potentials in the ventromedial hypothalamus following direct stimulation of the basomedial amygdala (*4*). Laboratory born and reared rhesus monkeys also vary in their response to novelty. Those who are slow to explore show higher heart rates in unfamiliar settings and larger increases in plasma cortisol following separation from the mother or peers than do animals who are much less avoidant (*5*). The total corpus of evidence suggests that both animals and children who consistently show an initial avoidance of or behavioral restraint to novelty display distinctive behavioral and physiological profiles early in development, implying the influence of genetic factors.

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Inhibited and Uninhibited Children

Our laboratory has used a longitudinal design in the study of three cohorts of Caucasian children from working- and middle-class Boston homes. The first two cohorts were selected at either 21 or 31 months of age to include approximately equal numbers of children who were either consistently shy, quiet, and timid (inhibited) or consistently sociable, talkative, and affectively spontaneous (uninhibited) when exposed to unfamiliar people, procedures, and objects in unfamiliar laboratory settings. About 15 percent of a total sample of 400 children evaluated was classified as belonging to one of the two extreme groups with similar proportions of boys and girls in each group (*6*).

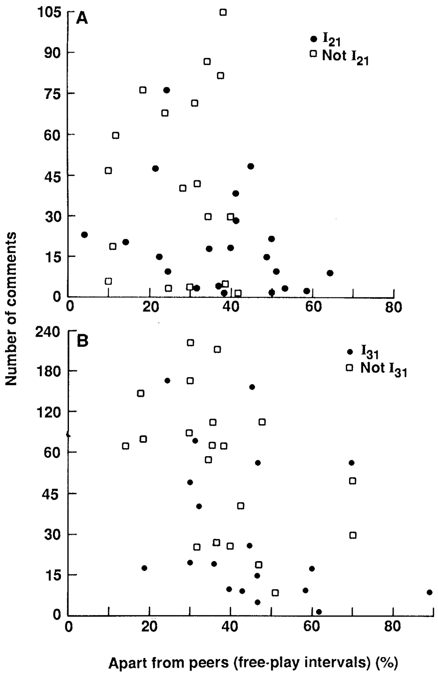
Descriptions of procedures. The children in cohort 1, selected at 21 months, were observed on two occasions with unfamiliar women and objects in several unfamiliar laboratory rooms. The major behavioral signs of inhibition coded from videotape were prolonged clinging to or remaining proximal to the mother, cessation of vocalization, and reluctance to approach or actual retreat from the unfamiliar events. The children who displayed these behaviors consistently across most incentives, as well as those who did not, were selected to form one group of 28 inhibited and another group of 30 uninhibited children.

The initial selection of children for cohort 2 at 31 months was based on behavior with an unfamiliar child of the same sex and age in the same laboratory playroom, with both mothers present, and a subsequent episode in which the child encountered an unfamiliar woman dressed in an unusual costume. The indexes of inhibition, similar to those used with cohort 1, were long latencies to play, speak, and interact with the unfamiliar child and woman, as well as long periods of time proximal to the mother. This selection process yielded 26 consistently inhibited and 23 consistently uninhibited children.

Each of these two cohorts was observed on three additional occasions. Cohort 1 was observed subsequently at 4, 5.5, and 7.5 years of age; cohort 2 at 3.5, 5.5, and 7.5 years, with about 20 percent attrition by the time of the last assessment at 7.5 years when there were 41 children in each cohort. The phenotypic display of the two temperamental tendencies changes with age because of learning and maturation. A 2-year-old will become uncertain in an unfamiliar room with unfamiliar objects, but older children require more potent incentives, especially unfamiliar children and adults. Thus, the specific laboratory procedures we used changed for the four evaluations.

The index of inhibition on the second assessment (3.5 or 4 years) was based on behavior in two, separate 40-minute laboratory play sessions with an unfamiliar child of the same sex and age with both mothers present. At 5.5 years the children in both cohorts were

Fig. 1. Relation between total number of spontaneous comments and the percentage of time each child was distant from a peer in a free-play situation at 7.5 years for (**A**) cohort 1 children selected at 21 months and (**B**) cohort 2 children selected at 31 months. The free-play intervals were longer for cohort 2; hence, the larger number of spontaneous comments. I, inhibited; Not I, uninhibited.



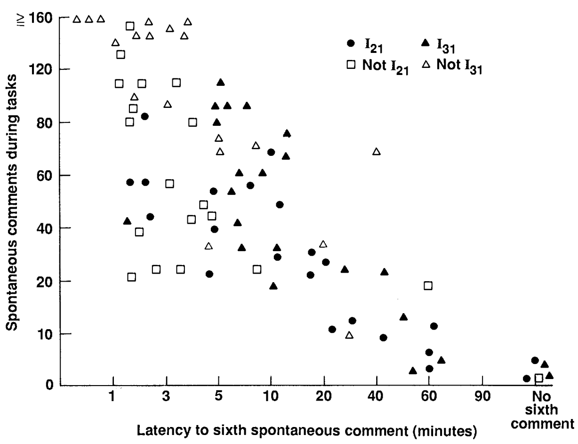


Fig. 2. Relation between latency to the sixth spontaneous comment and total number of spontaneous comments at 7.5 years for cohort 1 children selected at 21 months and cohort 2 children selected at 31 months. I, inhibited; Not I, uninhibited.

observed in four different unfamiliar situations. The indexes of inhibition, for each situation, were based on (i) long latencies to initiate play or interact with an unfamiliar child as well as time proximal to the mother in a laboratory playroom, (ii) spatial isolation and infrequent interaction with classmates in the child's school setting, (iii) long latencies to talk and infrequent spontaneous comments with a female examiner who administered a 90-minute cognitive battery (including recall and recognition memory, match to sample, and discrimination of pictures), and (iv) reluctance to play with novel toys suggestive of risk in an unfamiliar laboratory room (a large black box with a hole or a beam set at an angle to the floor). The theoretically relevant variables from each situation were aggregated to form a composite index of behavioral inhibition (*7*).

The index of behavioral inhibition at 7.5 years was based on two situations separated by several months. The first was a laboratory play situation involving seven to ten unfamiliar children of the same age and sex; a single unfamiliar child does not generate sufficient uncertainty in a child this old. Approximately 50 minutes was devoted to structured, competitive games and a total of 30 minutes to unstructured free-play intervals interposed between each of the games. The two variables indexing behavioral inhibition were infrequent spontaneous comments to the other children and long periods of playing or standing apart from any other child in the room. The second assessment context was an individual testing session with an unfamiliar female examiner. The two variables were latency to the sixth spontaneous comment to the examiner and the total number of spontaneous comments over the testing session. The results are similar if latency to any of the first six comments is used as the component of the index. The reliabilities between coders (correlation coefficients) for the variables quantified from videotapes were generally above 0.90 at each age.

Preservation of behavioral differences. The initial behavioral differences between inhibited and uninhibited children predicted theoretically reasonable derivatives at the older ages (the adjectives inhibited and uninhibited refer to the original classification at 21 or 31 months, unless stated otherwise). The slopes of the regression lines relating an index of inhibited behavior at one age to an index at a later age, which reflect the stability of behavior, ranged from 0.40 to 1.12 ($P < 0.01$). The standard error of the slopes ranged from 0.09 to 0.22 and the standard deviation of the values around the slope ranged from 0.45 to 0.83 (*8*). Each mother's rating of her child's shyness with unfamiliar people was only moderately related to the child's behavior in the laboratory (correlations between the two variables ranged from 0.3 to 0.6). Additionally, the mothers of inhibited children in both cohorts more often reported a history of excessive irritability, colic, and sleeplessness during the infant's first year.

Figure 1 illustrates values for children in each cohort on the two indexes of behavioral inhibition with the group of unfamiliar peers at age 7.5—that is, the percentage of time distant from any other child during the free-play intervals and total number of spontaneous comments. More inhibited, than uninhibited, children were above the median on the first variable and below on the second ($\chi^2 = 7.9$, $P < 0.05$ for cohort 1; $\chi^2 = 5.2$, $P < 0.05$ for cohort 2; and $\chi^2 = 15.2$, $P < 0.001$ for the pooled cohorts). A frequent scene during the play sessions was a cluster of three or four children playing close to each other, often talking, and one or two children standing or playing alone one to several meters from the center of social activity. These isolated, quiet children were typically those who had been classified as inhibited 5 or 6 years earlier (*9*).

After 4 years of age remaining quiet with an unfamiliar adult in an evaluative setting is an extremely sensitive sign of behavioral inhibition. The inhibited children were much less talkative with the examiner than uninhibited children during the testing session at 4 and 5.5 years. During the testing session with an unfamiliar female examiner at 7.5 years, 60 percent of the inhibited and 15 percent of the uninhibited children uttered their sixth spontaneous comment later in the session and, in addition, spoke less often than uninhibited children (based on median values for the two variables, $\chi^2 = 20.9$, $P < 0.0001$) (Fig. 2).

The mean of the two standardized indexes of inhibited behavior from the peer play procedure (proportional amount of time distant from peers and total number of spontaneous comments) was combined with the mean of the two standardized indexes from the testing situation (latency to the sixth spontaneous comment and total number of spontaneous comments; $r = 0.40$ between the two indexes) to yield an aggregate index of inhibition for the 41 children in cohort 1 at 7.5 years. Figure 3 illustrates the relation between this aggregate score and the original behavioral index. The predictive relation between the indexes at 21 months and 7.5 years had a slope of 0.50 ($P < 0.001$), with a standard error of 0.09 and a standard deviation of the values around the regression line of 0.56. A comparable analysis of cohort 2 data revealed a slope of 0.59

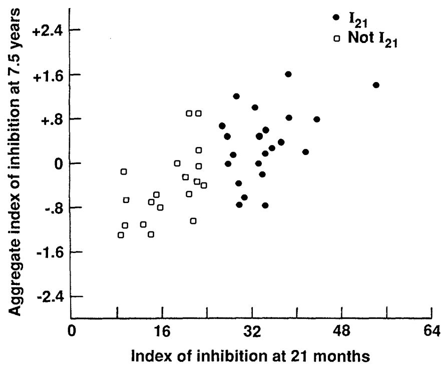


Fig. 3. Relation between the original index of inhibition at 21 months and the aggregate index of inhibition (*z* score) at 7.5 years for cohort 1 children. I, inhibited; Not I, uninhibited.

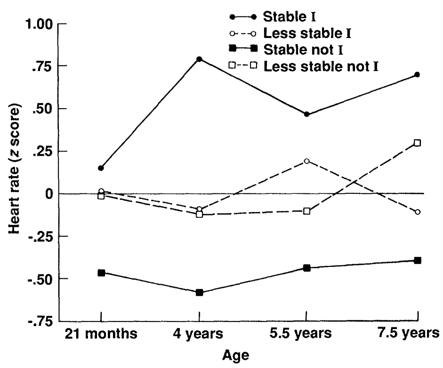


Fig. 4. Mean heart rate (*z* score) for cohort 1 children at each of the four assessments (stable I refers to 12 children who were inhibited at every age; less stable I, to 10 children who were inhibited originally but were uninhibited on one or more of the later assessments; stable not I, to 12 children who were consistently uninhibited; and less stable not I, to 7 children who were classified as uninhibited originally but were inhibited on one or more of the later assessments). The standard errors of the mean for each of the four groups at the four ages averaged 0.29, 0.26 for the consistently inhibited children, and 0.34 for the consistently uninhibited children.

($P < 0.001$) between the indexes at 3.5 and 7.5 years with a standard error of 0.12 and a standard deviation of the points around the line of 0.45. Furthermore, the children in both cohorts who had the most extreme scores on the original index were most likely to have remained behaviorally consistent through 7.5 years.

An unselected cohort. In a third longitudinal study, Caucasian middle-class children of both sexes were selected who were extreme on the two behavioral profiles. The children in cohort 3 were observed initially at 14 months ($n = 100$), and again at 20 ($n = 91$), 32 ($n = 76$), and 48 months ($n = 77$). The indexes of inhibition at 14 and 20 months were based on behavior with an unfamiliar examiner and with unfamiliar toys in laboratory rooms. The index of inhibition at 32 months was based on behavior in a 30-minute free-play situation with two other unfamiliar children of the same sex and age with all three mothers present. The index of inhibition at 48 months was based on behavior with an unfamiliar child of the same sex and age, with an unfamiliar examiner in a testing situation and in an unfamiliar room containing objects suggestive of risk. The original variation in inhibited behavior for the entire group at 14 months was correlated with the variation at 20 and 32 months ($r = 0.52$ and 0.44; $P < 0.01$), but the indexes at 14 and 20 months did not predict differences in behavioral inhibition at 4 years of age. However, when we restricted the analysis to those children who fell at the top and bottom 20 percent of the distribution of behavioral inhibition at both 14 and 20 months (13 children in each group), the two groups showed statistically significant differences at 4 years of age ($t = 2.69$, $P < 0.01$). Almost half the inhibited but 8 percent of the uninhibited group had a positive standard score on the index of inhibition at 4 years of age. This finding, together with the data from cohorts 1 and 2, implies that the constructs inhibited and uninhibited refer to qualitative categories of children. These terms do not refer to a behavioral continuum ranging from timidity to sociability in a volunteer sample of children, even though such a continuum can be observed phenotypically.

Physiology and Inhibition

As noted, intraspecific variation in behavioral withdrawal to novelty in rats, cats, and monkeys is often related to physiological reactions that imply greater arousal in selected hypothalamic and limbic sites, especially the amygdala (*3*). If this relation were present in humans, inhibited children should show more activity in biological systems that originate in these sites. Three such systems are the sympathetic chain, reticular formation with its projections to skeletal muscles, and the hypothalamic-pituitary-adrenal axis (*10*).

Sympathetic reactivity. Five potential indexes of sympathetic reactivity include a high and minimally variable heart rate, as well as heart rate acceleration, pupillary dilation, and norepinephrine level to psychological stress and challenge. We measured each child's heart period and heart period variability under both minimally stressful baseline conditions as well as during moderately stressful cognitive tasks on every one of the four assessments. Heart period variability was the average standard deviation of the interbeat intervals during the trials of the test episodes. Mean heart period and heart period variability for a multitrial episode were based on the values for the separate trials of that episode. Although we use the terms heart rate and heart rate variability in the text, all statistical analyses were performed on the heart period values.

Mean heart rate and variability were always inversely correlated—a higher heart rate associated with lower variability—under both relaxed conditions as well as during cognitive activity (product moment correlations were between −0.6 and −0.7). Individual differences in heart rate and variability were preserved from 21 months to 7.5 years in cohort 1 ($r = 0.62$, $P < 0.001$ for heart rate; $r = 0.54$, $P < 0.001$ for variability); from 31 months to 5.5 years for cohort 2 ($r = 0.59$, $P < 0.001$ for heart rate and $r = 0.61$, $P < 0.001$ for variability). Correlations are reported because the children were not selected to be extreme on the cardiac variables and both heart rate and variability were normally distributed at all ages. Further, the index of inhibited behavior was typically associated with a higher and more stable heart rate on the early evaluations (average $r = 0.4$), but on the last assessment at 7.5 years this relation was less robust ($r = 0.3$). However, the inhibited children with the highest heart rates on the first two assessments were more likely to have remained inhibited through 7.5 years than the inhibited children who had lower heart rates earlier. We computed for each child in cohort 1 a standard score representing his or her index of inhibition and heart rate on each of the four assessments. At every age the consistently inhibited children (those with positive standard scores on the index of inhibition on each assessment) and the consistently uninhibited children had the highest and lowest heart rates, respectively (Fig. 4).

Unusual fears at 5.5 and 7.5 years (violence on television or in movies, kidnappers, or going to the bedroom alone in the evening) were most frequent in inhibited children with the highest heart rates (60 percent of the group) and least frequent in uninhibited children with the lowest heart rates (no child in this group had any unusual or intense fears).

In addition, at every age inhibited children were more likely than uninhibited ones to show an increase in heart rate, about ten beats per minute, across the trials of a test or across the entire battery of cognitive tests (*7, 11*). This fact was also true for the cohort 3 children who had extreme scores on the index of inhibition at 4 years of age. The inhibited children were more likely to attain their maximal heart rate early in the testing session, usually during the first cognitive procedure following the initial baseline. We also evaluated, for the first time at 7.5 years in cohort 2 and 4 years in cohort 3, the change in heart rate when the child's posture changed from sitting to standing. Inhibited children showed a larger increase in mean heart rate (ten beats per minute) during a 60-second period than did uninhibited children, despite a slightly higher heart rate during the preceding sitting baseline. This result suggests that the inhibited children maintained a brisker sympathetic response to the drop in blood pressure that accompanies the rise to a standing position. In addition, the inhibited children in cohort 2 showed higher diastolic, but not a higher systolic, blood pressure during the testing session at 7.5 years, implying greater sympathetic tone in the vessels of the arterial tree.

Several months after the laboratory session with cohort 1 at 7.5 years we recorded the child's heart rate during one night of sleep. We eliminated the first and last hours of sleep on the assumption that sleep would be lighter during these times, and a continuous respiration record permitted elimination of epochs of active sleep. The mean quiet heart rate during sleep was 76 beats per minute, with a range of 59 to 92 beats, and there was no statistically significant relation between heart and respiration rate. The mean sleeping heart rate was correlated with heart rate obtained in the laboratory at each of the four ages ($r = 0.37$, 0.40, 0.61, and 0.49, $P < 0.05$). Although the sleep heart rate had only a low positive association with the aggregate index of inhibition at 7.5 years, two of the four components of the composite index of inhibition at 5.5 years (reluctance to play with novel toys suggestive of risk in an unfamiliar room and shy, restrained behavior with an unfamiliar peer) were associated with higher sleeping heart rates 2 years later ($r = 0.48$, $P < 0.01$; $r = 0.35$, $P < 0.05$).

Pupillary dilation, which is another potential index of sympathetic activity (*12*), was assessed only at 5.5 years. Although both cohorts showed a reliable increase in pupil size of about 0.3 millimeter to cognitive test items (an increase of about 5 percent), the inhibited children in both cohorts had larger pupil diameters during test questions as well as during the intervals between test items [$F(1, 269) = 20.9$, $P < 0.1$ for test trials; $F(1, 154) = 17.3$, $P < 0.001$ for periods before trials; F values based on repeated measures analysis of variance].

Muscle tension. Projections from limbic structures to the skeletal muscles of the larynx and vocal cords also appear to be at higher levels of excitability in inhibited children. Increased tension in these muscles is usually accompanied by a decrease in the variability of the pitch periods of vocal utterances, which is called perturbation (*13*). The increased muscle tension can be caused by discharge of the nucleus ambiguus as well as sympathetic activity that constricts arterioles serving the muscles of the larynx and vocal folds. Because the vocal cords do not maintain a steady rate as they open and close, the perturbations in the rate at which they open and close is a consequence of many factors, one of which is the degree of tension in the laryngeal muscles (*14*). We measured the vocal perturbation of single-word utterances at 5.5 years in cohort 1 and 3.5 years in cohort 2. The inhibited, compared with the uninhibited, children showed a significantly greater decrease in vocal perturbation when the single words were spoken under moderate as opposed to low stress. The inhibited children also showed less variability in the fundamental frequency of all the single-word utterances spoken during the episode (*15*).

Urinary norepinephrine. Norepinephrine is the primary neurotransmitter in the postganglionic synapses of the peripheral sympathetic nervous system. A urine sample collected from each child in cohort 1 at the end of the test battery at 5.5 years was tested for norepinephrine and its derivatives (normetanephrine, MHPG, and VMA) by mass fragmentography (*16*). Concentrations of each compound were transformed to micrograms per gram of creatinine, and a composite index of total norepinephrine activity was computed. There was a modest correlation between this index and inhibited behavior at both 4 and 5.5 years ($r = 0.34$, $P < 0.05$ with the index at age 4; $r = 0.31$, $P < 0.05$ with the index at age 5.5 years).

Salivary cortisol. In order to assess activity in the hypothalamic-pituitary-adrenal axis, samples of saliva were gathered on cohort 1 at 5.5 years when the child came to the laboratory, as well as at home on three mornings before breakfast and before the stress of the day had begun. Analysis of unbound cortisol in these saliva samples by a modification of the standard radioimmunoassay method revealed that the average cortisol level for the three morning home samples was correlated with the original index of inhibition ($r = 0.39$, $P < 0.05$) (*17*).

Aggregate of physiological variables. With the exception of heart rate and heart rate variability, correlations among the remaining physiological variables were low, ranging from -0.22 to $+0.33$ with a median coefficient of $+0.10$. This phenomenon has been noted by others (*18*). However, it is likely that an aggregate index of physiological activity might be more highly correlated with inhibited behavior because any single variable could be the result of a factor unrelated to the hypothetical processes mediating inhibited and uninhibited behavior. Pooling several indexes would dilute the contribution of any of these factors. For example, a child who did not belong to the inhibited category but who was highly motivated to solve the cognitive problems might show a high and minimally variable heart rate and a large pupil, but this child should show average cortisol levels and variability in the vocal perturbation index. Consider the following analogy. Body temperature, fatigue, thoracic discomfort, and pneumococci in the sputum are not highly correlated in a random sample of the population. But persons with high values on all four variables meet the criterion for a special disease category. We averaged the standard scores for eight peripheral psychophysiological variables gathered at 5.5 years on cohort 1 to create a composite index of physiological arousal (mean heart period, heart period variability, pupillary dilation during cognitive tests, total norepinephrine activity, mean cortisol level at home and in the laboratory, variability of the pitch periods of vocal utterances under cognitive stress, and the standard deviation of the fundamental frequency values of the vocal utterances). There was a substantial positive relation between this composite physiological index and the index of inhibition at every age ($r = 0.70$ with the index at 21 months and $r = 0.64$ with the index at 7.5 years of age).

Discussion

A majority of children who had been selected from a much larger sample at 1.5 or 2.5 years because they were extremely shy, quiet, and restrained in a variety of unfamiliar contexts became 7 year olds who were quiet, cautious, and socially avoidant with peers and adults, whereas a majority of children who had been selected to be extremely sociable and affectively spontaneous were talkative and socially interactive at 7 years of age. However, the preservation of these two behavioral styles, albeit modest and different in form at the two ages, holds only for children selected originally to be extreme in their behavior. The data from cohort 3 indicate that there is no predictive relation in an unselected sample between indexes of inhibited behavior assessed during the second and fourth years. Only when we restricted the analysis to the behavioral extremes did we find preservation of the two behavioral categories as well as an association between inhibition and both heart rate acceleration to mild stress and high early morning levels of salivary cortisol.

The behavioral differences between the two groups were most consistently associated with peripheral physiological variables implying greater sympathetic reactivity among the inhibited children, especially larger cardiac accelerations to cognitive activity and to a postural change from sitting to standing. We suggest, albeit speculatively, that most of the children we call inhibited belong to a qualitatively distinct category of infants who were born with a lower threshold for limbic-hypothalamic arousal to unexpected changes in the environment or novel events that cannot be assimilated easily. This hypothesis is consonant with comparable data gathered on rhesus monkeys (*5*), the views of a number of physiologists (*19*), and especially animal data implying that the amygdala is an important mediator of states which would be regarded as resembling anxiety or fear in humans (*20*). Although the reasons for the lower thresholds in limbic-hypothalamic sites are unclear, and likely to be complex, tonically higher levels of central norepinephrine, greater density of receptors for norepinephrine in these areas, or both are possible contributing factors (*21*). This suggestion is supported by evidence indicating a close covariation in free-moving cats between activity of the locus coeruleus, the main source of central norepinephrine, and acceleration of heart rate to the stresses of white noise and restraint (*22*).

However, we suggest that the actualization of shy, quiet, timid behavior at 2 years of age requires some form of chronic environmental stress acting upon the original temperamental disposition present at birth. Some possible stressors include prolonged hospitalization, death of a parent, marital quarreling, or mental illness in a family member. These stressors were not frequent in our samples. However, in both longitudinal cohorts, two-thirds of the inhibited children were later born while two-thirds of the uninhibited children were first born. An older sibling who unexpectedly seizes a toy, teases, or yells at an infant who has a low threshold for limbic arousal might provide the chronic stress necessary to transform the temperamental quality into the profile we call behavioral inhibition. Thus, it is important to differentiate between those children and adolescents who are quiet and restrained in unfamiliar social situations because of the influence of temperamental factors and those who behave this way because of environmental experiences alone. Physiological measures might be helpful in distinguishing between these two groups. We suspect that the contemporary construct of introversion, usually applied to adults, contains both types (*23*). Finally, we note that these data support Jung's claim, which Freud rejected, that temperamental factors contribute to the development of social anxiety and avoidance and to the symptoms of panic and agoraphobia that had been classified earlier in the century as components of hysteria (*24*).

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