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Research Article

Stability in Cognition Across Early Childhood

A Developmental Cascade

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ABSTRACT—***Children confront the formidable task of assimilating information in the environment and accommodating their cognitive structures to that information. Developmental science is concerned equally with two distinctive features of these processes: children's group mean level of performance through time and the standing of individual children through time. Prevailing opinion since the inception of the mental-measurement movement has been that individual development is unstable—that individual children change unpredictably in their abilities. We report results of a large-scale controlled, multivariate, prospective, microgenetic, 4-year longitudinal study that reveals a statistically significant cascade of species-typical cognitive abilities from infancy to childhood. Infancy is a recognizable starting point of life; we find that to a small but significant degree, infancy also represents a setting point in the life of the individual.***

Several profound and far-reaching questions about ontogenetic progress in human cognition still occupy developmental science. Among them, the issue of what connections obtain between early and later mental life looms large. These questions have been addressed historically through the use of traditional developmental sequences, scales, and schedules, which are valuable for defining normative growth, but have proved inconsistent with respect to long-term prediction (Bayley, 1949; Bornstein & Sigman, 1986; McCall & Carriger, 1993). Other infant cognitive assessments (like the one we employ here) have been marshaled from time to time and appear to have some predictive value (Bornstein, 1985b, 1998; Colombo, 2004; McCall & Carriger, 1993). However, the studies employing these methods have been criticized for the use of small sample sizes, inclusion of at-risk children, reliance on post hoc analyses, and failures to control critical endogenous or exogenous variables (e.g., Malcuit, Pomerleau, & Lamarre, 1988). Our goal in the large-scale, well-controlled, normative, prospective study we describe here was to obviate such criticism in search of a more definitive answer about developmental stability in individual mental life from babyhood. This study was novel in giving a key role to intermediate assessments (indirect effects) and controlling child temperament, parental education, and home environment so as to target unalloyed cognitive stability.

We based this study on the proposition that infants' encounters with the world centrally entail information processing. Contemporary theories in psychology depict human beings as information-processing organisms (Newell & Simon, 1972), and information processing is ubiquitous, is fundamental, and starts at birth in the individual's effort to make sense of the world and gain mastery over it. Information-processing ability in preverbal infants can be examined through the use of the infant-controlled habituation-test paradigm (Bornstein, 1985a, 1985b; Fantz, 1964), which we implemented in a sample of five hundred sixty-four 4-month-olds. When a stimulus first appears, a baby will normally orient and attend to it. If, however, that stimulus is made available continuously or is presented repeatedly, the baby's attention to it usually wanes. This decrement in attention, or habituation, is a broadly adaptive form of learning that typifies infants' everyday interactions with people and objects (Bornstein & Ludemann, 1989). Efficiency of habituation, as

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measured by infants' shorter total looking time to repeated stimuli than to novel stimuli, shows wide individual differences and is a stable characteristic in the short term (Bell, Slater, & ALSPAC Study Team, 2002; Bornstein, 1998; McCall & Carriger, 1993).

After habituation testing, we periodically traced variation in the children's development over the next 4 years, until they were of sufficient age to submit to a standardized assessment of psychometric intelligence. The function of intelligence is to gain information. We reasoned that the variation we found in 4-month-olds' information-processing capacity would be reflected in recurring longitudinal evaluations of conceptually related and age-appropriate cognitive tests. When the infants were 6 months old, we assessed a composite of their social, language, fine motor, and gross motor adaptive abilities via the Denver Developmental Screening Test (DDST; Frankenburg & Dodds, 1967); when the children were 18 months old, we tapped their sensory, motor, and mental performance via the Griffiths (1984) Mental Development Scales; when they were 24 months old, we evaluated their verbal competencies via the MacArthur Communicative Development Inventory: Words and Sentences (MCDI-WS; Fenson et al., 1993); and when they were 49 months old, we measured their psychometric intelligence via the Wechsler Preschool and Primary Scale of Intelligence–Revised[UK] Edition (WPPSI–R; Wechsler, 1990).

METHOD

Participants

This investigation was conducted as part of the Avon Longitudinal Study of Parents and Children (ALSPAC; Golding, Pembrey, Jones, & ALSPAC Study Team, 2001). All births in the former Avon Health Authority with an expected date of delivery between April 1, 1991, and December 31, 1992, were eligible, and more than 80% of the known births from the geographically defined catchment area were included, resulting in a total cohort of 14,138 surviving live births. From this population cohort, a random sample of 10% of the parents and babies who were born within the last 6 months of the enrollment period was invited for more intensive assessment. The potential participants for the present study were the 983 singleton infants in the 10% sample who attended the 4-month clinic. The final sample for the first wave of data collection consisted of 564 infants: 318 males and 246 females.[1] Table 1 summarizes their sociodemographic characteristics. All the children were term at birth (mean gestation = 39.9 weeks, SD = 1.2), of normal birth weight (M = 3,545.1 g, SD = 457.7), and healthy throughout the course of the study.

Principal Measures

The measures we selected to represent a developmental cascade of age-appropriate cognitive constructs began with information-processing efficiency and moved to adaptive responding, general mental development, language comprehension and production, and finally standardized psychometric intelligence. Testers and coders at each age were blind to children's performance at other ages.

4 Months

Each of the 983 infants participated in an infant-controlled habituation at age 4 months. The habituation stimulus was a black-on-white geometric pattern of four diamonds subtending 26° (height) × 20° (width). Each trial began when the infant looked at the stimulus and ended when the infant looked away for at least 2 s continuously; the infant was judged to have habituated when the duration of looking on any two successive trials (after the second trial) was less than one half the total duration of any two previous successive trials. After each infant reached the habituation criterion, the infant saw four paired test trials, each pair being shown until 10 s of looking time had accumulated. On the test trials, the familiar habituation stimulus was paired with a same-size novel stimulus, a random polygon; the two stimuli were equidistant from the center of the display. New, identical stimuli were displayed on a prehabituation and a posttest trial. The infant's looking time was measured on each trial. Experimental controls ruled out the possibility that decreased looking time to the familiar stimulus on the habituation and test trials was ascribable to response fatigue or to sensory adaptation: Infants who completed all procedures (n = 375) declined in looking during habituation ($p < .001$), showed a novelty response to the novel versus the familiar stimulus in the test ($p < .001$), and looked equally at the prehabituation and posttest stimuli (n.s.).

Infants who failed to reach the habituation criterion were eliminated from further analysis. The remaining five hundred sixty-four 4-month-olds were categorized as *completers* (n = 375), infants who completed the whole habituation task (i.e., habituating and then amassing 40 s of looking on the test), and *part-completers* (n = 189), infants who reached the habituation criterion but ended the session before the test was completed. The completers and part-completers did not differ on any demographic variables, with the exception that the completers were negligibly older than the part-completers (mean difference of 3.0 days) at the 4-month visit, $t(429) = 4.11$, $p < .001$.

Habituation efficiency (the total looking time required to reach the habituation criterion × −1) was used as the outcome measure for the habituation task because it was available for both completers and part-completers and has shown validity in other studies (Bornstein, 1998). A subgroup of this sample

[1]Children were eliminated from further study for the following reasons: failure to reach the habituation criterion (n = 358), loss of information because of computer or experimenter error (n = 7), and fussiness (n = 19). An additional 35 infants were excluded because of preterm (gestation at delivery < 37 weeks; n = 17) or postterm (gestation at delivery > 43 weeks; n = 1) delivery, low birth weight (≤ 2,500 g; n = 10), or diagnoses of developmental problems (e.g., autism, cerebral palsy; n = 7).

TABLE 1
Sociodemographic Characteristics of the Sample

Characteristic	Total sample *n*	Total sample *M*	Completers *n*	Completers *M*
Child's age at data collection (in months)				
Habituation	564	3.9 (0.2)	375	3.9 (0.2)
Denver Developmental Screening Test	526	6.3 (0.4)	349	6.3 (0.4)
Griffiths Mental Development Scales	457	18.3 (0.3)	296	18.3 (0.4)
MacArthur Communicative Development Inventory: Words and Sentences	471	24.1 (0.4)	317	24.1 (0.4)
Wechsler Preschool and Primary Scale of Intelligence–Revised^{UK}	420	48.9 (0.4)	277	48.9 (0.4)
Child's gender (% girls)	564	43.6	375	41.3
Birth order (%)	542		362	
1	247	45.6	168	46.4
2	177	32.7	115	31.8
3	82	15.1	55	15.2
4+	36	6.6	24	6.6
Mother's age at child's birth (in years)	564	28.9 (4.8)	375	28.8 (4.8)
Mother's education	537		360	
Certificate of Secondary Education	71	13.2%	48	13.3%
Vocational school	58	10.8%	30	8.3%
Ordinary level (secondary school completed)	194	36.1%	135	37.5%
Advanced level (college preparatory completed)	136	25.3%	93	25.8%
College degree	78	14.5%	54	15.0%
Mother's social class[a] (%)	449		308	
I (professional)	30	6.7	20	6.5
II (managerial and technical)	142	31.6	97	31.5
III NM (skilled nonmanual)	193	43.0	137	44.5
III M (skilled manual)	43	9.6	31	10.1
IV (partly skilled)	35	7.8	19	6.2
V (unskilled)	6	1.3	4	1.3

Note. Standard deviations are in parentheses.
[a]Social class was measured by the Registrar General's measure of social class, which is based on job status, associated education, and prestige (Office of Population Censuses and Surveys, 1990).

(n = 22) gave evidence of the 2-week short-term reliability of habituation efficiency, $r = .43$, $p < .05$, 95% confidence interval (CI) = .08–1.00 (Bell et al., 2002).

6 Months
When the infants were 6 months old, their mothers completed 42 items from the DDST (Frankenburg & Dodds, 1967) in questionnaires relating to four developmental areas of their infant's life: personal-social, fine motor-adaptive, language, and gross motor. Mothers responded *has not started yet* (0), *has only done it once or twice* (1), or *has done it often* (3) to each item.

18 Months
Trained psychologists administered the Griffiths (1984) Mental Development Scales to the children when they were 18 months old. This instrument assesses five areas of development: locomotor, personal-social, hearing and speech, hand-and-eye coordination, and performance. Scores were age adjusted and averaged to form an individual General Developmental Quotient (GQ).

24 Months
When the children were 24 months old, their mothers completed an adapted British English MCDI-WS (Fenson et al., 1993), specifying which words in a 123-item vocabulary checklist their child understood only (Comprehension score) or understood and said (Production score). The Comprehension score was the total number of words understood only, and the Production score was the total number of words both understood and said.

49 Months
Trained testers used the WPPSI–R (Wechsler, 1990) to assess the children's standardized psychometric intelligence at age 49 months.

Data-Analytic Plan and Preliminary Analyses
We used structural equation modeling (Bollen, 1989) to assess the value of 4-month habituation efficiency in predicting 49-month intelligence, taking into consideration both indirect effects on intervening abilities and a variety of control variables.

For a mediated, distal, developmental process, such as that between habituation efficiency in infancy and intelligence in middle childhood, a test of the indirect path between predictor and criterion is more sensitive, powerful, and theoretically appropriate than is a test of a simple direct relation between the two (Fry & Hale, 1996; Shrout & Bolger, 2002). We therefore hypothesized an indirect effect of habituation efficiency on intelligence, but not a direct effect.

Univariate distributions for all variables were examined for nonnormalcy and outliers (Fox, 1997). Habituation efficiency was reexpressed using a $\log_{10}$ transformation to approximate normality and reduce the number and influence of outliers. Bivariate plots based on pair-wise deletion procedures confirmed that all variables were linearly related. Missing data points were imputed using a two-stage expectation-maximization (EM) estimation of the structured model and the maximum likelihood (ML) function. In the first stage, an EM estimate is obtained for population means, variances, and covariances implied by the model; in the second stage, given the implied covariance structure, an estimate of the ML function is obtained. We imputed 13.3% and 10.6%, respectively, of the total data points for two families of models (described later in this section). Monte Carlo studies have demonstrated the general superiority of the structured-model EM method for recovering missing data in sample sizes of 100 or 500 with as much as 16% of the data missing (or in larger sample sizes with as much as 50% missing), especially in the case of normal or slightly nonnormal data that are missing completely at random (Gold & Bentler, 2000; Yuan & Bentler, 2000).

To evaluate the significance of regression coefficients for the final models, we report the standardized coefficients and appraise their probabilities using the critical ratios associated with the robust standard errors for the unstandardized coefficients. Model fit was assessed using multiple convergent indices, including the robust Yuan-Bentler (Y-B; Yuan & Bentler, 1998) scaled chi-square statistic (to obtain robust standard errors of parameters), robust comparative fit index (CFI), and root mean square error of approximation (RMSEA) and its 90% CI. Values of the CFI greater than .95 and values of the RMSEA greater than .06 were taken as indicative of a relatively good fit between the hypothesized model and the observed data. To enhance the cross-validation adequacy of the models, we monitored the Akaike information criterion (AIC; Akaike, 1987) for decreasing value in all nested models.

Two separate families of models were tested. Model 1 was the baseline model that included only habituation efficiency and the four longitudinal follow-up cognitive measures. In Model 2, child's temperament, mother's education, and a family Home Observation for Measurement of the Environment (HOME; Bradley & Caldwell, 1979) score were added to the baseline model to control for other endogenous and exogenous sources of stability (Bornstein, 1998). WPPSI–R Full Scale IQ and Verbal and Performance IQs (Wechsler, 1990) were evaluated separately in each family of models. Both families of models were also evaluated separately in completers ($n = 375$) and in the total sample (completers and part-completers, $N = 564$), and multisample analysis was performed across child gender. Because of space limitations, we report model results only for completers for Full Scale IQ; all other models showed equivalent patterns of results.[2]

RESULTS

Table 2 lists the means, standard deviations, and available number of observations for all measures for the total sample and for completers. Among completers, the zero-order correlations of habituation efficiency, DDST, GQ, MCDI-WS Production, and MCDI-WS Comprehension with 49-month Wechsler Full Scale IQ were .03 ($df = 274$, $p = .65$), .12 ($df = 264$, $p < .05$), .45 ($df = 245$, $p < .001$), .28 ($df = 27$, $p < .001$), and .29 ($df = 257$, $p < .001$), respectively.

Predictive Validity of Habituation Efficiency for Psychometric Intelligence

First, an a priori model in which each measure was a function only of the immediately preceding measure plus a random error was fit to the data for completers: Y-B $\chi^2(9) = 43.71$, $p < .001$, robust CFI = .95, RMSEA = .10, 90% CI = .07–.13. The overall chi-square test and RMSEA indicated that the model left considerable covariation unexplained. Examination of Lagrange multiplier tests revealed that substantial improvement in model fit was obtained by incorporating two additional paths into the model: a path from Griffiths GQ to WPPSI–R Full Scale IQ, $\chi^2(1) = 22.48$, $p < .001$, and a path from DDST to MCDI-WS latent variable, $\chi^2(1) = 11.02$, $p \leq .001$. Given the substantive meaningfulness of these two paths, a final model was respecified with the two respective parameters set free.

Figure 1 presents the standardized solution of the final, modified model. Goodness-of-fit indices for the final model were excellent: Y-B $\chi^2(7) = 6.54$, $p = .48$, robust CFI = 1.00, RMSEA = .00, 90% CI = .00–.06. The model reproduced observed correlations with an average absolute standardized error of .01. All paths were significant at $p \leq .05$. The indirect effect of habituation efficiency on WPPSI–R Full Scale IQ was significant (standardized indirect effect = .024, $p < .05$): Children who took less time to habituate at 4 months had higher Full Scale IQ scores at 49 months, with the effect mediated by all interim cognitive measures. (Adding a direct path from habituation efficiency to intelligence yielded a standardized path coefficient of .00, $p = 1.00$.)

Model-fit indexes for the final models with Verbal and Performance IQs were also excellent, and the indirect effects of

[2]A full report (including pair-wise covariance matrices, means, standard deviations, and sample sizes, and ML estimates of the means from Models 1 and 2 in completers and the total sample) is available from the first author.

TABLE 2
Descriptive Statistics for the Outcome and Control Variables

	Total sample			Completers		
Variable	*n*	*M*	*SD*	*n*	*M*	*SD*
Habituation (s)	564	39.81	41.42	375	44.05	42.65
Denver Developmental Screening Test (age-adjusted total score)[a]	526	69.44	12.23	351	69.01	12.39
Griffiths Mental Development Scales General Developmental Quotient[b]	443	108.55	8.32	290	108.00	8.09
MacArthur Communicative Development Inventory: Words and Sentences						
Comprehension	492	87.49	24.16	329	86.65	24.79
Production	492	61.39	34.17	329	60.25	35.12
Wechsler Preschool and Primary Scale of Intelligence–Revised[UKc]						
Full Scale IQ	417	104.86	14.59	276	104.33	13.99
Verbal IQ	417	100.15	13.89	276	100.01	13.24
Performance IQ	418	108.91	14.83	276	108.14	14.59
Carey Infant Temperament Questionnaire (age-adjusted mean score)						
Activity level	522	3.33	0.51	345	3.32	0.53
Rhythmicity	522	1.57	0.70	345	1.56	0.70
Approach	520	1.45	0.65	344	1.41	0.63
Adaptability	522	1.37	0.56	345	1.33	0.56
Intensity	521	2.50	0.58	345	2.47	0.58
Mood	520	1.77	0.63	344	1.77	0.61
Persistence	522	1.91	0.73	345	1.92	0.74
Distractibility	522	1.40	0.55	345	1.39	0.55
Sensory threshold	520	2.72	0.57	345	2.69	0.59
Home Observation for Measurement of the Environment (total score)	533	8.36	2.08	354	8.28	2.09

Note. Analyses were conducted on the transformed data; the table presents untransformed data.
[a]Total score may range from 0 to 126. Age correlated with total score, $r(524) = .22$, $p < .001$, so an age-adjusted total score was calculated.
[b]For this measure, $M = 100.1$ and $SD = 12.8$. [c]The standard score has $M = 100$, $SD = 15$.

habituation efficiency on the WPPSI–R Verbal and Performance IQs were both significant. Multisample models for girls and boys in which factor loadings, path coefficients, and variances and unique variances were constrained to be equal for girls and boys also yielded an excellent fit to the data, and the indirect effects of habituation efficiency on full-scale intelligence were significant for girls and boys alike. All the same results obtained for the total sample ($N = 564$).

Predictive Validity of Habituation Efficiency for Intelligence, Controlling for Child Temperament, Mother's Education, and Home Environment

Findings of stability so early in life can entice developmental scientists into believing that only processes endogenous to the child are at play. Apparent cognitive stability may be ascribable, however, to other endogenous processes or to exogenous experiences (Bornstein, 1998). That is, other endogenous noncog-

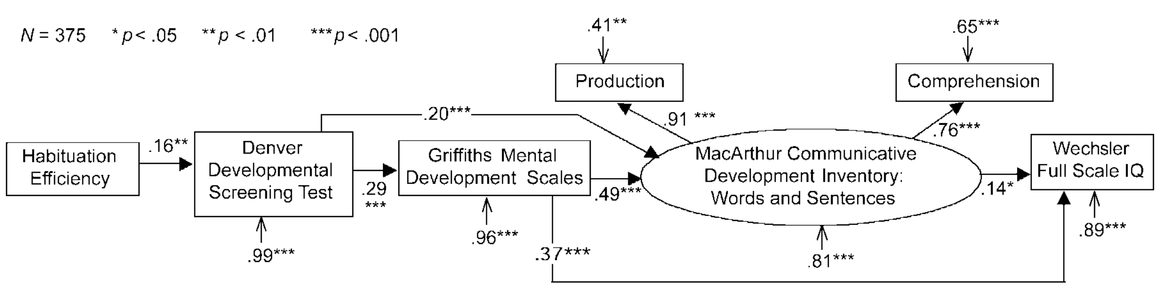

Fig. 1. Standardized solution for Model 1 based on the completers ($n = 375$). Numbers associated with single-headed arrows from one variable to another are standardized path coefficients. Numbers associated with short vertical arrows are error or disturbance terms.

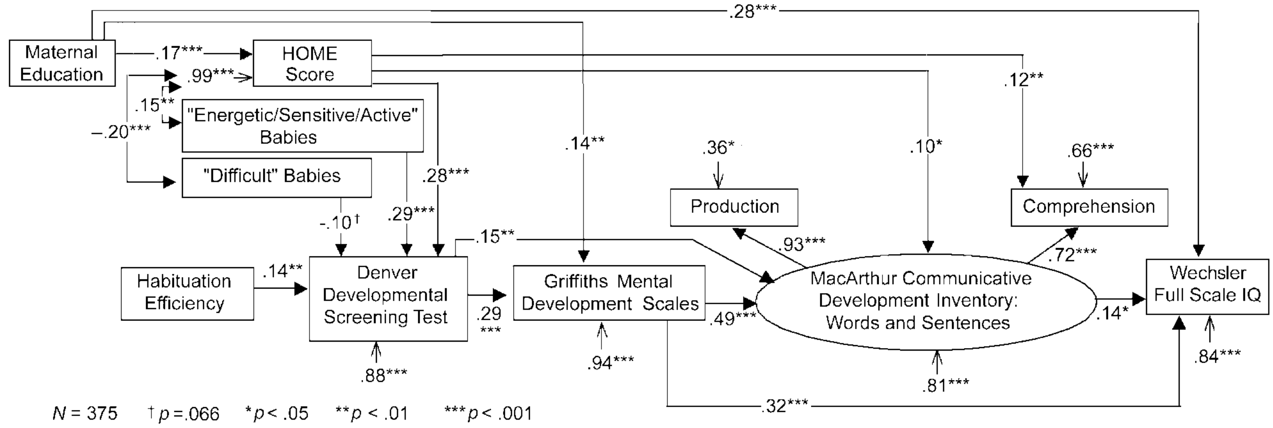

Fig. 2. Standardized solution for Model 2 based on the completers (n = 375). Numbers associated with single-headed arrows from one variable to another are standardized path coefficients. Numbers associated with short vertical arrows are error or disturbance terms.

nitive constructs (like temperament) that are moderately stable from infancy to childhood could contribute, at least in part, to the predictive association between habituation efficiency in infancy and intelligence in childhood. For their part, exogenous experiences manifestly influence development at every level of ontogenesis from cells to culture, and consistent experiences could likewise carry observed predictive effects. In early infancy, experience is provided by parents (Barnard & Solchany, 2002) and the infant's local environment (Bradley, 2002). The infant is never alone in development. Moreover, infants' attention is known to share unique (if moderate) variance with such exogenous variables (Bornstein & Tamis-LeMonda, 1994).

We therefore simultaneously assessed the possibilities that aspects of the child's temperament and that mothers' education and an effective and consistent stimulating environment might carry the association between habituation efficiency in infancy and intelligence in childhood. To characterize temperament, we used the Infant Temperament Questionnaire (ITQ; Carey & McDevitt, 1978), and to reduce the number of temperament variables, we extracted two principal components from the ITQ's nine temperament dimensions. The first principal component was best defined as "difficult," and the second component was labeled "energetic-sensitive-active." Cognitive environment at home was measured with a modified form of the HOME (Bradley & Caldwell, 1979). We added child temperament, mother's education, and the HOME score to the baseline model and reevaluated the predictive validity of habituation efficiency for Full Scale IQ.

Figure 2 shows the final model for completers, which fit the data well: Y-B $\chi^2(27) = 34.65$, $p = .15$, robust CFI = 1.00, RMSEA = .03, 90% CI = .00–.05. The model reproduced observed correlations with an average absolute standardized error of .02. The indirect effect of habituation efficiency on Full-Scale IQ remained significant (standardized indirect effect = .019, $p < .05$): Children who took less time to habituate at 4 months had higher Full Scale IQ at 49 months after taking child temperament, mother's education, and the home environment into consideration.

Model-fit indices for the final model with Verbal and Performance IQs were excellent, and the indirect effects of habituation efficiency on WPPSI–R Verbal and Performance IQs were both significant. The final baseline model fit equally well for girls and boys, and the indirect effects of habituation efficiency on WPPSI–R Full Scale IQ were also significant for both girls and boys after taking child temperament, mother's education, and the home environment into consideration. All the same results obtained for the total sample ($N = 564$).

In the model for completers only, the indirect effects from habituation efficiency, mother's education, HOME score, and DDST score to Wechsler Full Scale IQ were .019, .065, .051, and .133, $ps < .05, .01, .001$, and .001, respectively. The total effects (direct plus indirect effects) of these variables on Wechsler IQ were the same as the indirect effect for all variables with the exception of mother's education: The total effect of mother's education on Wechsler IQ was .35, $p < .001$.

DISCUSSION

Family influences and the external environment undoubtedly play key roles in children's cognitive growth. Human mental development is an open system, and human beings are in continuous interaction with their environment. However, a significant unique stability in children's mental development appears to be independent of other personal proclivities (temperament), as well as parenting and the home environment. Habituation efficiency in infancy predicts a small but significant degree of cognitive status in childhood, and the source of stability in that mental performance appears to reside in children themselves. The predictive relation we found is noteworthy, first, because of the time of initial test (4 months) and predictive duration (4 years) and, second, because our predictive coefficients likely underestimate true validity (on account of state variation among infants and error associated with mass testing). To address the issue of the robustness of the indirect effect, we estimated the standardized indirect effect in the final model with the 231 children who had no missing data. The estimated effect obtained was .022, $p = .02$, which is very close to the original estimate of .024. The bootstrapped bias-corrected 95% CI (MacKinnon, Lockwood, & Williams, 2004) of the standardized indirect effect using 1,000 resamples was .003 to .053.

We conclude that a developmental cascade obtains among measures of age-appropriate cognitive constructs in young children. We liken this cascade to a hierarchy of functions at different levels of aggregation (Lewontin, 2005). The circulation of the blood serves the function of cell respiration by bringing oxygen and removing waste products, so the heart may beat. But the contraction of muscles serves the function of making the heart beat, so the structure of muscle cells and their patterns of innervation are equally vital. In turn, the proteins actin and myosin subserve the shortening of individual muscle fibers. That is, a hierarchical cascade of vital functions obtains, and each level is uniquely important to life. Understanding the causes of individual differences means working at many loci, each of small effect, and with interactions among them. We also propose that a cascade of cognitive developmental achievements has predictive power from infancy to childhood. Fry and Hale (1996) and Colombo (2004) described similar systems approaches to how attention contributes to common measures of visual cognition across development.

Just as small variations in molecular structure can have surprisingly large effects on the functions of the organism, the indirect effect we detected was not large, but may represent individually small processes that cumulate in important outcomes (Abelson, 1985), and such small effects in the whole population can have substantial societal consequences. From a public-health perspective, subtle effects can influence the success of children in school and the cost of special-education services (Lester, LaGasse, & Seifer, 1998).

Habituation efficiency may indicate enhanced information processing—enhanced speed, accuracy, and completeness of mentally assimilating and accommodating environmental stimulation (Bornstein, 1998; Colombo, 2004; McCall & Carriger, 1993). This interpretation is supported by the facts that older babies habituate more efficiently than younger babies (Fantz, 1964), normally developing babies habituate more efficiently than babies at risk for cognitive developmental delay (Friedman, 1975), and simple stimuli engender more efficient habituation in babies than complex stimuli (Caron & Caron, 1969). The predictive value of habituation efficiency in infancy for childhood cognitive performance comports with this view.

Infants who habituate efficiently are infants who scan and pick up information economically, assimilate that information quickly, or construct memories more easily and faithfully than other infants. Children who successfully solve the perceptual, language, abstract reasoning, and memory tasks that are included in children's intelligence tests do likewise (Neisser et al., 1996). In turn, individual differences in information processing could reflect individual differences in some aspect of central nervous system functioning, such as speed of neurotransmission, which depends on myelinization, extent of dendritic branching, and neurochemical or biophysical parameters (Colombo, 2004). In addition, habituation and cognition could be linked through inhibition (McCall & Mash, 1995): When infants inhibit attending to familiar (or irrelevant) stimulation, they also liberate attentional and cognitive resources to deploy in new encounters with new stimulation in the environment.

Habituation is a window to the mind of the young child. In *Paradise Regained*, John Milton (1671/2001, IV, 220) opined that "the childhood shows the man." Our study shows that very young infants possess an active mental life that they bring to their own development. An infant's habituation performance does not fix his or her intelligence separately from temperament and experience, of course, but our study's large sample size; normative, multivariate, prospective, long-term, longitudinal design; and robust findings nonetheless demonstrate significant stability of individual differences across a cascade of abilities in human mental development from early life.

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REFERENCES

Abelson, R. (1985). A variance explanation paradox: When a little is a lot. *Psychological Bulletin*, *97*, 129–133.

Akaike, H. (1987). Factor analysis and AIC. *Psychometrika*, *52*, 317–332.

Barnard, K.E., & Solchany, J.E. (2002). Mothering. In M.H. Bornstein (Ed.), *Handbook of parenting: Vol. 3. Status and social conditions of parenting* (2nd ed., pp. 3–25). Mahwah, NJ: Erlbaum.

Bayley, N. (1949). Consistency and variability in the growth of intelligence from birth to eighteen years. *Journal of Genetic Psychology*, *75*, 165–196.

Bell, J.C., Slater, A., & ALSPAC Study Team. (2002). The short-term and long-term stability of non-completion in an infant habituation task. *Infant Behavior & Development*, *25*, 147–160.

Bollen, K.A. (1989). *Structural equations with latent variables*. New York: Wiley.

Bornstein, M.H. (1985a). Habituation of attention as measure of visual information processing in human infants: Summary, systematization, and synthesis. In G. Gottlieb & N.A. Krasnegor (Eds.), *Measurement of audition and vision in the first year of postnatal life: A methodological overview* (pp. 253–300). Norwood, NJ: Ablex.

Bornstein, M.H. (1985b). How infant and mother jointly contribute to developing cognitive competence in the child. *Proceedings of the National Academy of Sciences, USA*, *82*, 7470–7473.

Bornstein, M.H. (1998). Stability in mental development from early life: Methods, measures, models, meanings and myths. In F. Simion & G. Butterworth (Eds.), *The development of sensory, motor and cognitive capacities in early infancy: From perception to cognition* (pp. 301–332). Hove, England: Psychology Press.

Bornstein, M.H., & Ludemann, P.L. (1989). Habituation at home. *Infant Behavior and Development*, *12*, 525–529.

Bornstein, M.H., & Sigman, M.S. (1986). Continuity in mental development from infancy. *Child Development*, *57*, 251–274.

Bornstein, M.H., & Tamis-LeMonda, C. (1994). Antecedents of information-processing skills in infants: Habituation, novelty responsiveness, and cross-modal transfer. *Infant Behavior & Development*, *17*, 371–380.

Bradley, R.H. (2002). Environment and parenting. In M.H. Bornstein (Ed.), *Handbook of parenting: Vol. 2. Biology and ecology of parenting* (2nd ed., pp. 281–314). Mahwah, NJ: Erlbaum.

Bradley, R.H., & Caldwell, B.M. (1979). Home observation for measurement of the environment: A revision of the preschool scale. *American Journal of Mental Deficiency*, *84*, 235–244.

Carey, W.B., & McDevitt, S.C. (1978). Revision of the Infant Temperament Questionnaire. *Pediatrics*, *61*, 735–739.

Caron, A.J., & Caron, R.F. (1969). Degree of stimulus complexity and habituation of visual fixation in infants. *Psychonomic Science*, *14*, 78–79.

Colombo, J. (2004). Visual attention in infancy: Process and product in early cognitive development. In M.I. Posner (Ed.), *Cognitive neuroscience of attention* (pp. 329–341). New York: Guilford.

Fantz, R.L. (1964). Visual experience in infants: Decreased attention to familiar patterns relative to novel ones. *Science*, *146*, 668–670.

Fenson, L., Dale, P., Reznick, J.S., Thal, D., Bates, E., Hartung, J., Pethick, S., & Reilly, J. (1993). *The MacArthur Communicative Development Inventories: User's guide and technical manual*. San Diego, CA: Singular Publishing Group.

Fox, J. (1997). *Applied regression analysis, linear models and related methods*. Thousand Oaks, CA: Sage.

Frankenburg, W.K., & Dodds, J.B. (1967). Denver Developmental Screening Test. *Journal of Pediatrics*, *71*, 181–191.

Friedman, S. (1975). Infant habituation: Process, problems, and possibilities. In N. Ellis (Ed.), *Aberrant development in infancy: Human and animal studies* (pp. 217–239). New York: Halstead Press.

Fry, A.F., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. *Psychological Science*, *7*, 237–241.

Gold, M.S., & Bentler, P.M. (2000). Treatment of missing data: A Monte Carlo comparison of RBHDI, iterative stochastic regression imputation, and expectation-maximization. *Structural Equation Modeling*, *7*, 319–355.

Golding, J., Pembrey, M., Jones, R., & ALSPAC Study Team. (2001). The Avon Longitudinal Study of Parents and Children: I. Study methodology. *Paediatric and Perinatal Epidemiology*, *15*, 74–87.

Griffiths, R. (1984). *The abilities of young children: A comprehensive system of mental measurement for the first eight years of life*. Bucks, England: The Test Agency.

Lester, B.M., LaGasse, L.L., & Seifer, R. (1998). Cocaine exposure and children: The meaning of subtle effects. *Science*, *282*, 633–634.

Lewontin, R. (2005). *The triple helix: Gene, organism and environment*. Cambridge, MA: Harvard University Press.

MacKinnon, D.P., Lockwood, C.M., & Williams, J. (2004). Confidence limits for the indirect effect: Distribution of the product and resampling methods. *Multivariate Behavioral Research*, *39*, 99–128.

Malcuit, G., Pomerleau, A., & Lamarre, G. (1988). Habituation, visual fixation, and cognitive activity in infants: A critical analysis and attempt at a new formulation. *European Bulletin of Cognitive Psychology*, *8*, 415–440.

McCall, R.B., & Carriger, M.S. (1993). A meta-analysis of infant habituation and recognition memory performance as predictors of later IQ. *Child Development*, *64*, 57–79.

McCall, R.B., & Mash, C.W. (1995). Infant cognition and its relation to mature intelligence. *Annals of Child Development*, *10*, 27–56.

Milton, J. (2001). *Paradise lost; and paradise regained*. New York: New American Library. (Original work published 1671)

Neisser, U., Boodoo, G., Bouchard, T.J., Boykin, A.W., Brody, N., Ceci, S.J., Halpern, D.F., Loehlin, J.C., Perloff, R., Sternberg, R.J., & Urbina, S. (1996). Intelligence: Knowns and unknowns. *American Psychologist*, *51*, 77–101.

Newell, A., & Simon, H.A. (1972). *Human information processing*. Englewood Cliffs, NJ: Prentice-Hall.

Office of Population Censuses and Surveys. (1990). *Standard occupational classification*. London: HMSO.

Shrout, P.E., & Bolger, N. (2002). Mediation in experimental and nonexperimental studies: New procedures and recommendations. *Psychological Methods*, *7*, 422–445.

Wechsler, D. (1990). *Wechsler Preschool and Primary Scale of Intelligence–Revised^{UK} Edition*. San Antonio, TX: The Psychological Corp., Harcourt Brace.

Yuan, K.-H., & Bentler, P.M. (1998). Normal theory based test statistics in structural equation modelling. *British Journal of Mathematical and Statistical Psychology*, *51*, 289–309.

Yuan, K.-H., & Bentler, P.M. (2000). Three likelihood-based methods of mean and covariance structure analysis with nonnormal missing data. *Sociological Methodology*, *30*, 165–200.

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