Published in final edited form as:

Psychol Sci. 2013 October ; 24(10): 1906–1917. doi:10.1177/0956797613479974.

Physically Developed and Exploratory Young Infants Contribute to Their Own Long-Term Academic Achievement

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Abstract

A developmental cascade defines a longitudinal relation in which one psychological characteristic uniquely affects another psychological characteristic later in time, separately from other intrapersonal and extrapersonal factors. Here, we report results of a large-scale ($N = 374$), normative, prospective, 14-year longitudinal, multivariate, multisource, controlled study of a developmental cascade from infant motor-exploratory competence at 5 months to adolescent academic achievement at 14 years, through conceptually related and age-appropriate measures of psychometric intelligence at 4 and 10 years and academic achievement at 10 years. This developmental cascade applied equally to girls and boys and was independent of children's behavioral adjustment and social competence; mothers' supportive caregiving, verbal intelligence, education, and parenting knowledge; and the material home environment. Infants who were more motorically mature and who explored more actively at 5 months of age achieved higher academic levels as 14-year-olds.

Keywords

academic achievement; adolescent development; cognitive development; infant development

A key goal of contemporary developmental science is mapping temporal trajectories from early characteristics to mature phenotypes. Some relations between infant capacity and later status may be obscured because they are displaced in time, and others may go unnoticed because surface manifestations of different characteristics at different developmental periods appear unrelated. However, much of development consists of hierarchically organized abilities subsuming one another (Thelen & Smith, 1994). An implication of this systems

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Author Contributions

M. H. Bornstein and J. T. D. Suwalsky developed the underlying study, and M. H. Bornstein and C.-S. Hahn designed the study concept. Testing and data collection were performed under the supervision of J. T. D. Suwalsky. C.-S. Hahn performed the data analysis. All authors contributed to the interpretation of the results, wrote sections of the final manuscript, and approved the final version of the manuscript for submission.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Supplemental Material

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perspective is that earlier emerging characteristics in development lay foundations for later appearing characteristics and likely exert some impact on still later ones. It could be, therefore, that age-specific fundamental abilities in infancy, such as motor maturity and active exploration, underpin more sophisticated capacities, such as intelligence, cognition, and academic achievement, later in life.

This construal of the course of human development has been likened to a cascade (Masten & Cicchetti, 2010). A *developmental cascade* is a unique longitudinal relation among intrapersonal characteristics. By intrapersonal characteristics, we mean constructs, structures, functions, or processes in the individual. By unique longitudinal relation, we mean that one characteristic affects another over time distinct from intrapersonal characteristics in other domains and from extrapersonal factors. In a developmental cascade, an early characteristic initiates spreading effects across the domain that eventuate in the phenotype. For a mediated, distal, developmental process between predictor and criterion, such as between motor-exploratory competence in infancy and academic achievement in adolescence, cascades constitute sensitive and theoretically appropriate relations (Campos et al., 2000; Shrout & Bolger, 2002).

Previous predictive cascade analyses beginning in early life have focused on socially at-risk, minority, low-socioeconomic-status (SES), and relatively small samples. Usually initiated in late infancy, they have also been confined to short-term prediction and have not controlled potential confounds. Thus, published findings from infancy have been equivocal with respect to when cascades begin, how long they endure, and whether they generalize to the broader population. An exception is a large-scale British community sample study that demonstrated a developmental cascade between infants' habituation efficiency and adolescents' academic achievement through a series of intervening measures that also controlled relevant extrapersonal factors (Bornstein, Hahn, & Wolke, 2013).

The present study focused on motor-exploratory competence in infancy as a cascade catalyst of academic achievement in adolescence. Developmentalists have historically linked infant motor development to the growth of the mind. Gesell (1929) concentrated on the beginnings of prehension and object manipulation in infancy, and Piaget (1970) grasped the fundamental significance of sensorimotor activity as a foundation of knowing. Motor maturity and active exploration in infancy have since been associated empirically with advanced cognitive abilities in childhood: For example, 5-month activity has been related to 13-month attention and play (Tamis-LeMonda & Bornstein, 1993), 4-month movement to 2-year performance on the second edition of the Bayley (1993) Scales of Infant Development (Rose-Jacobs, Cabral, Beeghly, Brown, & Frank, 2004), 6-month psychomotor status to 2-year developmental profiles (McCall, Hogarty, & Hurlburt, 1972), 4-month Bayley Psychomotor Development Index (PDI) scores to 6-year visual-motor integration (Siegel, 1989), 8-month Bayley PDI and 1-year motor development to 7-year intellectual level (Broman, 1989), and 3-month motor control to 8-year attention (Friedman, Watamura, & Robertson, 2005). It has been argued that emerging motor-exploratory competence affords new learning experiences about the environment through object and social interactions. For example, upright self-sitting promotes coupling visual inspection and object manipulation because gaze is steadied during reaching, and hands are liberated from the need to support

(Bertenthal & Von Hofsten, 1998). Infants who stabilize their bodies so that their arms and heads can move can hold an object with one hand and finger it with the other, transfer an object from hand to hand, and so on. Infants experimentally given early experiences with postural control or object engagement later explore objects and perform means-end behaviors more than infants not given such experiences (Lobo & Galloway, 2008).

Guided by the literature, we expected that more advanced motor-exploratory competence in infancy would result in more advanced academic achievement in adolescence, through a series of intervening cognitive characteristics. The study of infants' motor-exploratory competence provides a test of developmental cascades by highlighting how individual variation in emerging skills can have systemwide consequences for later functioning (see the Supplemental Material available online). We studied adolescents' academic achievement as a phenotype criterion because it is an important developmental marker per se and has significant implications for still later educational and vocational success (Deary, 2012; Sternberg, Grigorenko, & Bundy, 2001). In a nutshell, our large-scale, normative, prospective, long-term, longitudinal, multivariate, multisource, controlled study was designed to trace a developmental cascade from motor-exploratory competence in infancy to academic achievement in adolescence.

Method

Participants

Altogether, 375 European American families were recruited when their firstborn children were 5 months old. One child's data set was identified as a multivariate influential case, contributing disproportionately to parameter estimates, and was removed. Reported statistics are thus based on 374 families in the final study sample. Children were healthy firstborns, 46% were girls and 54% were boys, and the mean ages in the sample were 5.37 months ($SD = 0.21$, $n = 373$), 4.05 years ($SD = 0.09$, $n = 254$), 10.33 years ($SD = 0.15$, $n = 228$), and 13.87 years ($SD = 0.27$, $n = 184$), respectively, at the first, second, third, and fourth assessment waves. At the first wave, mothers averaged 29.07 years of age ($SD = 6.53$, range = 13.91–46.01). Families represented a full range from lower to upper SES on the Hollingshead (1975) scale ($M = 49.23$, $SD = 13.76$, range = 14–66; full range of the Hollingshead scale is 8–66; Bornstein, Hahn, Suwalsky, & Haynes, 2003). See the Supplemental Material for the rationale behind recruiting European American participants.

Procedures

Infant motor-exploratory competence at 5 months—An hour of infant-mother behavior was recorded in the home to maximize ecological validity, and the first 50 min were coded using a mutually exclusive and exhaustive coding system to quantify frequency and duration of infant and mother behaviors to the nearest 0.10 s. Infant and mother behaviors were coded independently. (Data for five cases for which codeable time totaled less than 50 min, but more than 40 min, were prorated.) Infant motor-exploratory competence was a latent variable composed of indicators from infant motor maturity and exploratory activity. Motor maturity had two underlying indicators, movement and balance, constructed from four scales ordered with respect to their appearance in ontogeny:

prelocomotion in the upper and lower body, locomotion, and sitting. Prelocomotion-upper body was defined as the ability to control and coordinate the upper body while in a prone position and was rated on a scale from 1 (*lifts head and shoulders for more than 5 consecutive seconds*) to 5 (*able to reach with one arm, shift weight, and remain balanced*). Prelocomotion-lower body was defined as the ability to control and coordinate the lower body while in a prone position and was rated on a scale from 1 (*lies with legs extended and hips resting on the supporting surface*) to 4 (*assumes the full crawl position with weight supported on knees and lower legs*). Locomotion was deliberate, unassisted movement on a scale from 1 (*lifts legs when placed in a supine position*) to 11 (*actively creeps across the room*). Sitting consisted of the ability to control the body while in a sitting position on a scale from 1 (*sits with back rounded and head unsteady when fully supported in an inclined sitting position*) to 8 (*rotates from prone position to a balanced sitting position with weight on buttocks and without assistance*).

For each consecutive 10-min observation interval, each infant was assigned the highest level of each motor ability that was observed. If the infant was never in the physical position necessary to exhibit a given skill during an interval, no rating was made for that skill. Consistent with the theoretical understanding that prelocomotion-upper body, prelocomotion-lower body, and the locomotion scales index a single dimension of motor development, one indicator of the infant motor-maturity score, movement, was used. Movement was defined as the highest level of the prelocomotion-upper body, prelocomotion-lower body, and locomotion scale scores. Balance, the other indicator included in calculating the infant motor-maturity score, indicated the highest level of sitting observed.

Exploratory activity assessed infants' active exploration of the environment with two indicators: extent and efficiency of exploration. Extent of exploration concerned objects mouthed or touched as the mean standard aggregate of the variety (the number of different objects that were within infant reach), density (the mean number of objects within infant reach per consecutive 5-min time unit), and consistency (the number of consecutive 5-min time units in which any object was within infant reach). Efficiency of exploration was the mean standard aggregate of the proportion of variety, density, and consistency of objects the infant mouthed or touched. Tables S1, S2, and S3 in the Supplemental Material provide operational definitions and reliability information for all behavior codes; also see Supplementary References.

Child intellectual functioning at 4 and 10 years—At age 4 years, five subscales of the revised version of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-R; Wechsler, 1989) were administered; at 10 years, eight subscales of the third edition of the Wechsler Intelligence Scale for Children (WISC-III; Wechsler, 1991) were administered. Scaled score totals used for calculating full-scale IQ scores were prorated.

Child academic achievement at 10 and 14 years—Three subscales of the revised version of the Woodcock-Johnson Psycho-Educational Battery (WJ-R) Test of Achievement (Woodcock & Mather, 1989) were used to assess academic achievement at 10 years, and

four subscales of the WJ-R were administered at 14 years (Table 1). Standard scores were used in analysis.

Covariates

We controlled for covariation between behavioral adjustment and cognitive-academic achievement in the child as well as for the possibility that child social competence influenced performance during experimenter-administered assessments. To do this, we used the Preschool Behavior Questionnaire (PBQ; Behar & Stringfield, 1974) at 4 years; the Socialization domain on the Vineland Adaptive Behavior Scales (VABS; Sparrow, Balla, & Cicchetti, 1984) at 4, 10, and 14 years; and the Child Behavior Checklist (CBCL; Achenbach, 1991) at 10 and 14 years. We also assessed the possibilities that mothers' corresponding behaviors and aspects of the home environment during the 5-month observation influenced infant behaviors and that maternal verbal intelligence, education, and parenting knowledge influenced child cognitive-academic achievement (see the Supplemental Material).

Preliminary analyses and analytic plan

We fit structural equation models using maximum-likelihood functions and followed the mathematical models in EQS software (Version 6.1; Bentler, 1995; Bentler & Wu, 1995). Bivariate plots, based on pairwise deletion procedures, confirmed that all variables were linearly related. Data were missing completely at random—Little's test, $\chi^2(218, N = 374) = 231.76$, n.s.—and were imputed in EQS using a two-stage expectation-maximization estimation of the structured model and the maximum-likelihood function (Jamshidian & Bentler, 1999). Prior to analysis, all variables were examined for univariate normality (Tabachnick & Fidell, 2007). Infants' efficiency of exploration was raised to the third power to approximate normality and reduce the number and influence of outliers. In the course of fitting structural equation models, Mardia (1970) coefficients of multivariate kurtosis were evaluated. No significant problems of nonnormality emerged.

Model fit was assessed using the robust Yuan-Bentler (Y-B) scaled chi-square statistic, robust comparative fit index (CFI), and root-mean-square error of approximation (RMSEA). Cutoff values of approximately .95 for CFI and .06 for RMSEA are indicative of a relatively good fit between the hypothesized model and observed data (Hu & Bentler, 1999). We gave greater weight to the incremental fit indices than to chi-square results because chi-square is sensitive to sample size (Cheung & Rensvold, 2002) and the size of the correlations in the model (Miles & Shelvin, 2006).

We first fit an a priori cascade model on the full sample. Afterward, we performed multiple-group analysis on girls and boys (see the Supplemental Material). For multiple-group models, we report the difference in chi-square statistics and CFI values for nested models. If the change in chi-square results (χ^2) between the unconstrained and constrained models was nonsignificant ($p > .05$) and the change in CFI (Δ CFI) was less than or equal to .01 (Cheung & Rensvold, 2002; Vandenberg & Lance, 2000), the model was deemed to fit equally well in pairs of groups. The 5-month motor-exploratory-competence latent variable consisted of two domains, infant motor maturity and exploratory activity. We conducted a

post hoc analysis to identify domains that might underlie the joint cascade effects of infant motor-exploratory competence on adolescents' academic achievement. Finally, we reevaluated the cognitive cascade model controlling for key variables and third-variable causes.

Results

Tables 1 through 3 list the means and standard deviations for all measures. All means fell ± 1 standard deviation from means reported in normal or standardization samples of children and adolescents of similar ages as those in our study. We first fit a measurement model of the 5-month motor-exploratory-competence latent variable with balance as the marker indicator. Model fit indices were good, with all factor loadings significant at the .01 level or better—scaled Y-B $\chi^2(2, N = 374) = 2.05, p = .36$, robust CFI = 1.00, RMSEA = .00, 90% confidence interval = [0.00, 0.10].

An a priori model was created in which infant movement, balance, and extent and efficiency of exploration loaded on a single motor-exploratory-competence latent variable, the 10- and 14-year WJ-R scales loaded on two separate latent variables, and each child measure was a function of the immediately preceding measure; this model fit the data—robust Y-B $\chi^2(60, N = 374) = 173.64, p < .001$, robust CFI = 1.00, RMSEA = .00. The model reproduced observed correlations with an average absolute standardized error of .03. Figure 1 presents the standardized solution of this model. (Given that WJ-R scales were measured at both 10 and 14 years, we allowed for shared measurement errors between cross-time within-construct measures. The pairwise variance-covariance matrix of all variables in this model is presented in Table S4 in the Supplemental Material.) The longitudinal cascading effect of 5-month motor-exploratory competence on 14-year academic achievement was significant, $\beta = 0.12, p < .05$: Infants who were more motorically mature and who explored their environment more actively at 5 months had higher intellectual functioning at 4 and 10 years, and higher academic achievement at 10 and 14 years.

Cross-time predictions among motor-exploratory competence, intelligence, and academic achievement did not differ between girls and boys (see the Supplemental Material). The 5-month motor-exploratory-competence latent variable consisted of indicators that assessed domains of motor maturity (balance and movement) and exploratory activity (extent and efficiency of exploration). We conducted a post hoc analysis to identify domains of the 5-month-competence latent variable that might underlie cascade effects. Two structural equation models were evaluated in which motor maturity (shown in Fig. 2) and exploratory activity (shown in Fig. 3), respectively, were separately evaluated as the predictor variables in the longitudinal cascade models. Results indicated that both motor maturity and exploratory activity were significant predictors of the long-term outcomes: The indirect effects of motor maturity and exploratory activity on 14-year academic achievement were .27 and .13, respectively, $ps < .05$.

We then evaluated correlations of mothers' corresponding parenting behaviors and material provisioning of the home environment at 5 months with observed infant motor maturity and exploratory activity. We also analyzed the correlations of child problem behaviors and social

competence at 4, 10, and 14 years with concurrent cognitive-academic outcome measures. At age 5 months, mothers' promotion of infant physical development correlated with infant balance, $r(365) = .27, p < .001$, and mothers' promotion of infant exploration correlated with infants' extent and efficiency of exploration, $r(370) = .46$ and $.22$, respectively, both $ps < .001$. Further, mothers' material support correlated with infants' extent of exploration, $r(371) = .64, p < .001$. At age 4 years, children's WPPSI-R Full-IQ score correlated with PBQ Total Disturbed Behavior score, $r(240) = -.30, p < .001$, and VABS Communication score, $r(228) = .25, p < .001$. At age 10 years, children's CBCL Total Problems scale score correlated with WISC-III Full-IQ score, $r(181) = -.16, p < .05$, and WJ-R Calculation score, $r(176) = -.22, p < .01$. At age 14 years, children's CBCL Total Problems scale score and VABS Communication score correlated with WJ-R Dictation score, $r(155) = -.17$ and $r(172) = .17$, respectively, $ps < .05$, and WJ-R Applied Problems score, $r(156) = -.26, p < .001$, and $r(173) = .21, p < .01$, respectively. Further, CBCL Total Problems scale score correlated with WJ-R Passage Comprehension score, $r(156) = -.18, p < .05$. No other significant correlations emerged between potential covariates and child cognitive-academic outcomes. We computed adjusted scores for child variables at all four ages, removing their shared variances with significant covariates.

To test the predictive ability of infant motor-exploratory competence on later achievement controlling for covariates, we reevaluated the cascade model (Fig. 1) using covariate-adjusted scores and adding mothers' verbal intelligence, education, and parenting knowledge as exogenous variables. Figure 4 shows that the final covariate model fit the data—robust Y-B $\chi^2(94, N = 374) = 191.97, p < .001$, robust CFI = 1.00, RMSEA = .00. This model reproduced observed correlations with an average absolute standardized error of .03. The standardized estimate of predictive ability of 5-month motor-exploratory competence to 14-year academic achievement was $.11, p < .05$, controlling for child behavioral adjustment and social competence, mothers' corresponding parenting behaviors, and material provision of infants' home environment at 5 months, as well as maternal verbal intelligence, education, and parenting knowledge.

Discussion

In this large-scale, normative, prospective, 14-year longitudinal, multivariate, multisource, controlled study, we found that motor-exploratory competence in infancy initiates a developmental cascade that affects subsequent levels of child intellectual functioning that, in turn, help to shape academic achievement in adolescence. The variety of controls indicates that this predictive pathway resides in children themselves. The findings are consistent with a systems approach to development in which primary abilities constitute a foundation and formative building blocks for later functioning. Many accounts of development posit the contributions of more elementary earlier emerging skills for the formation of more integrative later emerging capacities (Thelen & Smith, 1994). We liken this developmental cascade to a hierarchy of functions at different levels of aggregation (Lewontin, 2005).

To our knowledge, few other studies of the predictive ability of motor-exploratory competence in infancy have begun so early and extended across so many years of development. As reviewed previously, research connects infant motor maturity and active

exploration with short-term gains in psychological functioning. Provocatively, the population-based Finnish Jyväskylä Longitudinal Study, in which infant motor development was evaluated together with other factors, yielded conclusions similar to ours: Infants whose motor development was relatively more advanced during the first year of life had larger vocabularies as young children at 3 and 5 years of age and were better readers at age 7 (Viholainen et al., 2006). Conversely, data from the Medical Research Council National Survey of Health and Development (the British 1946 birth cohort; $N = 3,083$) showed that delayed gross motor development in infancy (ages at standing and walking) predicted risk of reading impairment at age 11 years, even after confounds were controlled for (Gaysina, Maughan, & Richards, 2010).

These kinds of long-term spreading results can be framed within a systems perspective on development. Exploring and learning about the world are intertwined. As we measured it, motor-exploratory competence typifies infants' everyday interactions with objects and people, and it also appears to serve as a foundation for cognitive functioning in childhood and academic achievement in adolescence. A more motorically mature and actively exploring baby likely elicits more opportunities for interaction, richer contacts with novel aspects of the environment, more joint attention, and more exposure to referential language. In turn, learning is attuned to affordances during manual or oral exploration (Adolph, Eppler, Marin, Weise, & Clearfield, 2000; Bourgeois, Khawar, Neal, & Lockman, 2005). Postural control has also been implicated in advances in object exploration. The onset of self-sitting (maintaining balance with hands freed from serving as supports) antecedes eye-hand coordination and controlled reaching (Bertenthal & Von Hofsten, 1998). Learning naturally flows from the achievement of such motor milestones. Infants who can sit can more easily hold and manipulate objects and are more capable than same-age nonsitting infants at perceptual tasks (Soska, Adolph, & Johnson, 2010). Active visualmanual exploration also provides information about the infants' own role in controlling events. Development of control influences perception, and the interdependence between action and perception has implications for further development. With functionally mature prehension guided by cognition, the child comes to recognize that the self, not others, controls actions and that movements can be planned and directed to activity in the service of different needs. Advanced sensorimotor behaviors also draw caregivers into interaction with the infant. As independent self-control emerges and develops, infants thus discover new facts about themselves and their environment, about what information in the environment is relevant, and about the consequences of objects and events.

Developing motor skills and exploration efficiency influence how infants gather information about properties, objects, and events in the environment (Lockman, 2000). For example, infants who command more proficient manual-exploration skills can extract subtle differences in object properties, whereas infants who cannot yet perform the same actions show less nuanced perceptions of the material properties of objects (Striano & Bushnell, 2005). Developmental advances in exploration facilitate perception and cognition by helping infants to detect the properties and affordances of objects more readily. As infants become more adept at manipulation, they appear to pay more attention to the actions of objects in the world. For instance, in an audiovisual preference task, 5.5-month-olds with more proficient

manipulation skills matched sounds to object movements more successfully than did infants with less proficient skills (Eppler, 1995). Infants who look at and hold objects are more likely to disambiguate two objects in contact with each other as distinct. At 3 months, before they normally grasp and manually explore objects, infants who were fitted with Velcro “sticky mittens” and encouraged to pick up objects lined with matching Velcro showed accelerated object-manipulation skills and more interest in objects after the mittens were removed relative to infants in a control group. Early experience with object exploration also influences 3-month-olds’ perceptions of other people’s actions with objects: Relative to control subjects, infants with such sticky-mitten experience showed more sensitivity to an actor’s goal of reaching for an object (Sommerville, Woodward, & Needham, 2005).

Developmentally advanced infants are better positioned to seek out opportunities for perceptual, cognitive, communicative, and social stimulation—experiences that then feed back into fostering children’s further development. This orientation reaffirms the importance of motor-exploratory competence for psychological development because it operates consistently, effectively, and perhaps causally at the age when almost all infants become developmentally prepared for such experience.

Of course, proximal as well as distal exogenous factors also influence the growth of academic achievement. Because every phenotypic characteristic likely has many determinants, it is necessary to take into account many potential sources of influence before it is possible to assign predictive ability to any one, as we did here. Moreover, some variation in human intelligence and, perhaps, academic achievement may also be attributable to genetic factors (Deary, 2012), which we did not measure.

Developmental science has a long history of linking achievements in infants’ motor-exploratory competence with enhancements in perceptual and cognitive abilities. Piaget (1970) theorized that mental life builds hierarchically on earlier developing abilities and (more specifically) proposed that infants’ developing motor actions and exploration of the world are foundational for later learning. But many developmentalists have also maintained that human performance at different stages of life varies qualitatively, that infancy stands apart from the balance of the life course, and that development from infancy is unstable and noncontinuous. Our large-scale, normative, prospective, 14-year longitudinal, multivariate, multisource, controlled study and the cascade analysis that we brought to bear on the data it yielded demonstrate that individual differences in infant motor-exploratory competence initiate a connected cascade across age-appropriate abilities that eventuates in adolescent academic achievement. In essence, infants bring competencies to their own long-term development, motor-exploratory competence being an important one. (Information-processing efficiency in infancy is another; Bornstein et al., 2013.) These competencies do not fix a child’s intelligence or an adolescent’s achievement apart from other factors, such as personality and experiences, of course. Indeed, our analyses revealed independent and unique contributions of select exogenous factors to eventual adolescent academic achievement.

Cascades refer to the cumulative consequences for development of spreading effects among domains. Theoretically, these effects are directional; practically, their consequences are not

transient and appear to inflect the trajectory of development. Motor-exploratory competence in infancy is a catalyst for adolescent academic achievement.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Fig. 1.

Standardized solution for the cascade model showing the influence of motor-exploratory competence at 5 months on academic achievement at 10 and 14 years ($N = 374$). Values associated with single-headed arrows are standardized path coefficients, and values associated with double-headed arrows are standardized covariance estimates. Values associated with dependent variables are error variances or disturbance and represent the amount of variance not accounted for by paths in the model. Asterisks show significant paths, results, or differences between paths ($*p < .05$, $***p < .001$). Marker indicators of the latent variables are indicated with a superscript(^a).

Fig. 2.

Standardized solution for the cascade model showing the influence of motor maturity at 5 months on academic achievement at 10 and 14 years ($N = 374$). Values associated with single-headed arrows are standardized path coefficients, and values associated with double-headed arrows are standardized covariance estimates. Values associated with dependent variables are error variances or disturbance and represent the amount of variance not accounted for by paths in the model. Asterisks show significant paths, results, or differences between paths (* $p < .05$, ** $p < .01$, *** $p < .001$). Marker indicators of the latent variables are indicated with a superscript(^a).

Fig. 3.

Standardized solution for the cascade model showing the influence of exploratory activity at 5 months on academic achievement at 10 and 14 years ($N = 374$). Values associated with single-headed arrows are standardized path coefficients, and values associated with double-headed arrows are standardized covariance estimates. Values associated with dependent variables are error variances or disturbance and represent the amount of variance not accounted for by paths in the model. Asterisks show significant paths, results, or differences between paths ($*p < .05$, $***p < .001$). Marker indicators of the latent variables are indicated with a superscript^(a).

Fig. 4.

Standardized solution for the final cascade model showing the influence of motor-exploratory competence at 5 months on academic achievement at 10 and 14 years, with potential covariates added ($N = 374$). Values associated with single-headed arrows are standardized path coefficients, and values associated with double-headed arrows are standardized covariance estimates. Values associated with dependent variables are error variances or disturbance and represent the amount of variance not accounted for by paths in the model. Asterisks show significant paths, results, or differences between paths ($*p < .05$, $**p < .01$, $***p < .001$). Marker indicators of the latent variables are indicated with a superscript^(a).

Table 1

Descriptive Statistics for Measures Evaluating Motor Maturity, Exploratory Activity, Intellectual Functioning, and School Achievement at the Four Waves of the Study

Variable and measure	<i>M</i>	<i>SD</i>
5 months		
Motor maturity		
Balance	4.79	1.16
Movement	5.61	1.25
Extent of exploration (Z aggregate score)	0.00	0.90
Variety of objects mouthed or touched	7.85	4.11
Density of objects mouthed or touched	1.52	0.80
Consistency of objects mouthed or touched	6.99	2.13
Efficiency of exploration (Z aggregate score)	0.00	0.85
Proportion of variety of objects mouthed or touched	0.76	0.18
Proportion of density of objects mouthed or touched	0.60	0.18
Proportion of consistency of objects mouthed or touched	0.87	0.16
4 years		
Wechsler Preschool and Primary Scale of Intelligence, Revised (Wechsler, 1989) ^a	111.69	16.19
Block Design subtest ^b	10.57	2.95
Picture Completion subtest ^b	12.83	2.51
Arithmetic subtest ^b	11.02	2.76
Information subtest ^b	11.94	2.87
Similarity subtest ^b	10.67	2.53
10 years		
Wechsler Intelligence Scale for Children (Wechsler, 1991) ^a	117.59	14.68
Block Design subtest ^b	12.35	3.28
Picture Arrangement subtest ^b	11.08	3.62
Coding subtest ^b	11.17	3.04
Picture Completion subtest ^b	11.51	2.89
Arithmetic subtest ^b	12.73	3.86
Information subtest ^b	13.90	3.10
Vocabulary subtest ^b	13.69	3.11
Similarities subtest ^b	13.72	2.65
Woodcock-Johnson Psycho-Educational Battery–Revised (Woodcock & Mather, 1989) Test of Achievement		
Letter-Word Identification subtest ^a	115.95	14.18
Passage Comprehension subtest ^a	116.60	11.04
Calculation subtest ^a	118.49	17.94
14 years		

Variable and measure	<i>M</i>	<i>SD</i>
Woodcock-Johnson Psycho-Educational Battery–Revised Test of Achievement		
Letter-Word Identification subtest ^a	114.65	13.82
Passage Comprehension subtest ^a	119.14	16.93
Applied Problems subtest ^a	117.95	17.93
Dictation subtest ^a	99.07	16.11

^aThe mean standard score for this measure is 100 (*SD* = 15).

^bThe mean standard score for this measure is 10 (*SD* = 3).

Table 2

Measures Assessing Potential Covariates Regarding Child Behavioral Adjustment and Social Competence at 4, 10, and 14 Years

Measure and age group	<i>M</i>	<i>SD</i>
Preschool Behavior Questionnaire (Behar & Stringfield, 1974) at 4 years	14.69	4.94
Child Behavior Checklist (Achenbach, 1991)		
10 years	22.94	13.06
14 years	23.95	12.04
Child Social Competence: Vineland Adaptive Behavior Scale (Sparrow, Balla, & Cicchetti, 1984), Socialization Domain ^a		
4 years	100.20	9.09
10 years	97.35	12.79
14 years	98.71	11.75

^aThe mean standard score for this measure is 100 (*SD* = 15).

Table 3

Measures Assessing Potential Covariates Regarding Mothers' Corresponding Behaviors With Their Infants, Maternal Verbal Intelligence, Education, and Parenting Knowledge

Measure	<i>M</i>	<i>SD</i>
Promotion of motor development	0.12	0.09
Encouragement of balance	0.20	0.16
Encouragement of movement	0.03	0.05
Promotion of exploration (Z aggregate score)	0.00	0.91
Duration (min)	5.01	4.00
Frequency	30.64	19.23
Material support (Z aggregate score)	0.00	0.60
Quantity of objects provided		
Variety	10.47	5.53
Density	2.66	1.44
Consistency	7.95	1.87
Quality of objects provided		
Responsiveness	9.10	1.44
Number of highly responsive objects	1.21	1.21
Proportion of highly responsive objects	0.13	0.15
Maternal verbal intelligence: Peabody Picture Vocabulary Test-Revised (Dunn & Dunn, 1981) ^a	108.19	16.95
Maternal education ^b	5.47	1.43
Parenting knowledge: Knowledge of Infant Development Inventory (MacPhee, 1981) ^c	0.80	0.08

^aThe mean standard score for this measure is 100 (*SD* = 15).

^bTotal possible scores for this measure range from 1 to 7.

^cPossible scores for this measure range from 0 to 1.