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How many pathways underlie socioeconomic differences in the development of cognition and achievement?

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ABSTRACT

Children whose parents are more highly educated enjoy greater age-linked gains in cognitive abilities and academic achievement. Different researchers have typically focused on different outcomes, and the extent to which parental education relates to multiple child outcomes via a single developmental pathway has received little empirical attention. This issue was examined by applying common factor structural equation models to a large (N = 4810) nationally representative sample of kindergarten through 12th grade children, who were measured on 6 distinct cognitive abilities and 5 distinct forms of knowledge and academic achievement. Results indicated that a single pathway accounted for the relations between parental education and age differences in children's cognitive abilities. However, additional unique pathways were necessary to account for the relations between parental education and age differences in academic knowledge and mathematics. These results suggest that while socioeconomic differences are largely manifested in global aspects of cognitive development, they have incremental relations with some forms of academic achievement.

Indices of socioeconomic status (SES), such as parental educational attainment, are routinely linked with higher levels of cognitive performance and academic achievement throughout development. SES is associated with higher performance on general indices of cognitive ability (Ceci, 1996) and academic achievement (Sirin, 2005; White, 1982), and on specific indices of mathematics (Carneiro, Meghir, & Parey, 2007), reading (Carneiro et al., 2007), language and vocabulary (Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005; Petrill, Pike, Price, & Plomin, 2004), visuospatial processing (Noble et al., 2007), episodic memory (Noble et al., 2007), and working memory (Evans & Schamberg, 2009). With these associations now well-established, researchers are refocusing their efforts on clarifying the mechanisms through which socioeconomic differences in cognition and achievement emerge over the course of development. For instance, a number of researchers have focused on distinguishing between social selection mechanisms, in which the same traits that influence parental SES (e.g. intelligence, work ethic, motivation) are inherited by children and influence their cognitive development, and social causation mechanisms, in which the environmental conditions under which children born to low SES parents live (e.g. poor nutrition, lower quality social stimulation) impede their cognitive development (Huston & Bentley, 2010; Lubinski, 2009; Scarr, 1992; Strenze, 2007). However, one basic, descriptive question that has until now been largely overlooked is the extent to which the SES-related differences that have been identified for many different forms of cognition and achievement represent differences in a single global developmental process with far reaching effects versus differences in many different developmental processes. Answering this question is crucial for determining the extents to which the same set of mechanisms is sufficient for explaining SES-related differences in many different cognition and achievement outcomes, or different sets mechanisms are necessary for explaining SES-related differences in each individual cognition and achievement outcome.

There are a number of possible explanations for the observation that family socioeconomic status is associated with the development of very many cognition and achievement outcomes. One possibility is that the associations are reflections of associations with the development of a broader dimension of general cognitive ability. Under this scenario, socioeconomic status has a singular relation with general cognitive development, and performance levels in more specific domains are related to SES solely by virtue of their partial reliance on general functions. For example, deficits in the development of general cognitive ability would result in deficits in memory, mathematics skills, and spatial reasoning, simply because general cognitive ability plays a role in each of these domains. A second possibility is that socioeconomic differences in many outcomes reflect socioeconomic differences in the development of many separable, domain-specific, processes. Under this scenario, SES is independently and directly related to the development of different cognitive functions for different reasons. For example, when parents help children with their homework, reading skills might be more likely to benefit than would visuospatial processing ability. Finally, it is possible that SES relates to both domain-general and domain-specific processes. This hybrid scenario is particularly plausible

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given that the results of factor analyses of multivariate cognition and achievement data consistently indicate both that general a dimension underlies variation in many different domains of functioning, and that specific dimensions underlie variation in particular domains and not others (Carroll, 1993; Rhemtulla & Tucker-Drob, 2011; Tucker-Drob, 2009). Examining SES in the context of a multivariate approach is necessary, however, to test the extents to which SES relates to development via domain-general and domain-specific pathways. Previous investigations of socioeconomic differences in cognitive development have rarely analyzed data from multiple outcomes simultaneously. Even when multiple outcomes are measured, they are often analyzed separately.

The goal of the current project was to test the extents to which socioeconomic differences in age trends in eleven different forms of cognition and achievement can be attributed to a domain-general developmental pathway and to domain-specific pathways. Identifying the extents to which socioeconomic differences in cognition and achievement are manifested via global cognitive development and the development of multiple domain-specific cognitive functions will help to delineate what types of mechanistic accounts will be necessary to ultimately explain how socioeconomic differences in cognition and achievement emerge over development. In order to address these questions I fit three structural equation models to multivariate age-heterogeneous data from a nationally representative sample of children in the United States. The first model allows parental education to individually relate to age-related differences in each specific ability, but does not provide for mediation by a common factor (general cognitive ability). The second model allows parental education to only relate to age-related differences in the common factor, but does not allow parental education to directly relate to age-related gains in the specific abilities. In other words, this second model requires parental education to relate to age-related differences in the specific abilities entirely through differences in the common factor. The third, hybrid, model allows parental education to relate to age-related differences in the common factor and, where needed, to incrementally relate to age-related differences in specific abilities. Using this series of models, one can ask the theoretical question of whether SES relates to age-related gains in specific abilities exclusively by way of its relations to gains in general cognitive ability or whether SES relates to age-related gains in specific abilities even after adjusting for age-related gains in general cognitive ability.

1. Materials and methods

1.1. Participants

Data for this study come from the standardization sample of the Woodcock–Johnson III (WJ-III) Tests of Cognitive Abilities and the WJ-III Tests of Achievement (Woodcock, McGrew, & Mather, 2001). Participants were recruited using a three-stage stratified sampling procedure to be nationally representative of the United States population, as indexed by the 2000 census projections (McGrew & Woodcock, 2001). Moreover, individual subject weights were used in all analyses to correct for any insufficiencies in achieving this goal. Because this article focuses on child development, analyses were limited to the grade school (K-12) participants from the WJ-III sample up to 21 years of age ($N = 4810$). The vast majority of participants were between 5 and 18 years of age. Age was centered at 5 (the typical age at kindergarten entry) for all analyses. The age distribution, prior to centering, is presented in Table A1 of Appendix A.

1.2. Measures

Descriptive statistics for the study variables are presented in Table 2. Participants were measured on eleven theoretically and empirically distinguishable domains of cognition (Visual–Spatial Thinking, Abstract Reasoning, Speed of Processing, Short-Term Memory, Long-Term Retrieval, Auditory Processing) and achievement (Reading, Writing, Mathematics, Academic Knowledge, and General Knowledge). Scores for each of these domains were derived from up to three individual tests from the WJ-III Tests of Cognitive Abilities and the WJ-III Tests of Achievement (see Table 1). Scores are on a W scale, which is derived using 1 parameter

Table 1
Descriptions of measures of broad cognitive functions and academic achievement areas.

Cognition/achievement domain	Measure	Description
Visual–Spatial Thinking ($r = .80$)	Spatial relations	Identify the pieces needed to construct a specified shape.
	Picture recognition	Identify previously presented pictures within a field of distracting pictures.
Fluid Reasoning ($r = .95$)	Concept formation	Identify, categorize, and determine rules from a complete stimulus set.
	Analysis-synthesis	Learn and apply novel symbolic formulations to determine the missing components of puzzles.
Processing Speed ($r = .92$)	Visual matching	Quickly locate and circle two identical numbers in a row of numbers.
	Decision speed	Quickly locate and circle two conceptually related pictures in a row of pictures.
Short-Term Memory ($r = .87$)	Numbers reversed	Recall a series of numbers from immediate awareness in reverse sequence.
	Memory for words	Repeat a list of unrelated words in the sequence presented.
Long-Term Retrieval ($r = .87$)	Visual–auditory learning	Learn and recall pictorial representations of words.
	Retrieval fluency	Name as many examples as possible from a specified category.
Auditory Processing ($r = .89$)	Sound blending	Synthesize phonetic units.
	Auditory attention	Identify auditorily presented words in the presence of increasing intensities of background noise.
Comprehension Knowledge ($r = .94$)	Verbal comprehension	Name pictured objects, select synonyms and antonyms, and complete verbal analogies.
	General information	Identify where specified objects can be found, and what specified objects are typically used for.
Academic Knowledge ($r = .88$)	Science, social studies, and humanities subtests	Pointing responses on early items. Oral responses on later items.
Reading ($r = .93$)	Letter–word identification	Identify printed letters and words orally.
	Reading fluency	Read printed statements rapidly and reply true or false.
	Passage comprehension	Identify a missing key word to make a written passage make sense.
Writing ($r = .94$)	Spelling	Spell orally presented words.
	Writing fluency	Formulate and write simple sentences rapidly.
	Writing samples	Write meaningful sentences for a given purpose.
Mathematics ($r = .95$)	Calculation	Perform mathematical calculations of various types.
	Math fluency	Add, subtract, or multiply rapidly.
	Applied problems	Perform mathematical calculations to solve orally presented problems.

Note: Adapted from Table 4-2 of WJ-III Technical Manual (McGrew & Woodcock, 2001), as in Tucker-Drob (2009). Composite score reliability estimates (r) are from Mather and Woodcock (2001a) and Mather and Woodcock (2001b).

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Table 2
Variable intercorrelations, means, and standard deviations.

Variable	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	Mean	Standard deviation
1. General Knowledge	1.000													502.035	26.093
2. Spatial-Visualization	0.727	1.000												499.831	12.592
3. Abstract Reasoning	0.854	0.729	1.000											498.694	23.624
4. Processing Speed	0.832	0.738	0.811	1.000										501.223	39.164
5. Short-Term Memory	0.799	0.679	0.789	0.782	1.000									500.765	28.588
6. Long-Term Retrieval	0.837	0.743	0.832	0.827	0.786	1.000								499.733	9.054
7. Auditory Processing	0.799	0.669	0.752	0.761	0.751	0.766	1.000							500.574	13.760
8. Reading	0.908	0.740	0.854	0.913	0.831	0.859	0.803	1.000						496.961	52.284
9. Mathematics	0.885	0.746	0.863	0.906	0.817	0.844	0.767	0.938	1.000					500.154	32.363
10. Writing	0.885	0.734	0.842	0.908	0.822	0.85	0.791	0.959	0.933	1.000				498.41	27.923
11. Academic Knowledge	0.944	0.721	0.832	0.822	0.785	0.827	0.778	0.891	0.882	0.872	1.000			502.341	29.907
12. Parental Education	0.265	0.145	0.212	0.07	0.175	0.162	0.187	0.163	0.136	0.146	0.239	1.000		3.611	0.964
13. Age	0.813	0.661	0.713	0.842	0.692	0.710	0.672	0.824	0.842	0.822	0.804	0.032	1.000	10.865	3.861

Note: The means for parental education and age were calculated prior to centering these variables.

logistic item response theory scoring. The W scale has interval measurement properties such that at any level of performance (a) a difference between person ability and item difficulty (ability minus difficulty) of 0 corresponds to 50% probability of success, (b) a difference between person ability and item difficulty of 10 corresponds to a 75% probability of success, and (c) a difference between person ability and item difficulty of −10 corresponds to a 25% chance of success.

For the current project, the average of maternal and paternal education was used as an index of socioeconomic status. As Huston and Bentley (2010, p. 420) have discussed, parental education is a central component of SES, is highly correlated with other aspects of socioeconomic advantage, and, of all the possible indices of SES commonly used, is "one of the best predictors of children's intellectual functioning." For the current sample, maternal and paternal education were reported by parents on a five point scale. 1 = less than fifth grade, 2 = less than high school diploma, 3 = high school graduate, 4 = 1 to 3 years college, 5 = bachelors degree or higher. Maternal and paternal education correlated at approximately $r = .5$. For the analyses reported below, the parental education index was centered at its mean. The distribution of this index, prior to centering, is presented in Table A2 of Appendix A.

1.3. Analytical methods

Analyses made use of Mplus software (Muthén & Muthén, 1998–2007) for full information maximum likelihood estimation of structural equation models (SEMs). SEM's are used to simultaneously estimate the parameters of systems of regression equations that relate multiple variables. Regressions can involve variables that have been measured directly, and those that are implied by the data (e.g. latent factors, or random effects). The basic SEM used for the current investigation simultaneously estimates regressions of the eleven different outcomes on age (and-age squared to account for nonlinear age trends), SES, the interaction between age and SES, and a common factor. The age by SES interaction is used to test for socioeconomic differences in the age trends in the eleven outcomes. The common factor represents a dimension of individual differences that is shared across the eleven outcomes (i.e. general cognitive ability or *g*). The variation in performance in each test that cannot be accounted for by the common factor can be attributed to a combination of domain-specific aspects of test performance and measurement error. Of interest here is the extent to which the common factor mediates the influence of the age by SES interaction on the eleven outcomes, or whether direct influences of the age by SES interaction on the domain-specific aspects of test performance are necessary. This is examined by fitting three classes of models (Muthén, 1989).

1.3.1. Independent pathways model

In this model each of the eleven outcomes, Y_k, is directly regressed onto the interaction term and the other terms of the model. This is written as:

$$Y_k = \tau_k + \alpha_{1,k} \cdot age + \alpha_{2,k} \cdot age^2 + \beta_{1,k} \cdot SES + \beta_{2,k} \cdot SES \cdot age + \lambda_k \cdot F + u_k \quad (1)$$

where the subscript k indicates that a term is specific to each outcome, such that τ is an outcome-specific regression intercept, α_1 and α_2 represent the linear and nonlinear influences of age on each outcome, β_1 represents the main effect of parental education (*SES*) on performance on each outcome, β_2 represents socioeconomic differences in the age trends in each outcome, λ represents the relation of each outcome to the common factor *F*, and the *u*'s represent variation in each outcome that is not accounted for by the other terms in the model. *Age*, age^2, *SES*, and $SES \cdot age$ intercorrelate, but *F* and u_k do not. In this model, parental education is assumed to relate to each outcome through a different developmental pathway. Given that eleven independent pathways are estimated for the effects of parental education on age-related differences in each outcome, this model lacks parsimony. Nevertheless, it is important both as a baseline model, and for producing unrestricted estimates of the parental education-specific age trajectories that a more parsimonious model will have to reproduce.

1.3.2. Common pathway model

In this model the eleven outcomes are not directly regressed onto the interaction term. Rather, the single common factor is regressed onto this term. Any effects of the interaction term on the eleven outcomes are therefore indirect. That is, the $SES \cdot age$ interaction only relates to the eleven outcomes by way of a single relation with the common factor.[1] Because this model imposes strong restrictions on the route through which parental education can relate to age differences in the cognitive outcomes, this model is the most restrictive (and hence most parsimonious) account of the effects of parental education on cognitive development, and is sensitive to misfit. This model is written in multilevel notation as

$$Y_k = \tau_k + \alpha_{1,k} \cdot age + \alpha_{2,k} \cdot age^2 + \beta_{1,k} \cdot SES + \lambda_k \cdot F + u_k \quad (2)$$

[1] For theoretical reasons, two exceptions were made a priori. First, u_{reading} and u_{writing} were allowed to correlate. Second, $u_{\text{general knowledge}}$ and $u_{\text{academic knowledge}}$ were allowed to correlate. These substantially benefited model fit, but did not affect the major findings reported here.

and

$$F = \beta_2 \cdot SES \cdot age + s, \quad (3)$$

where s is a residual.

1.3.3. Common plus independent pathways model

In this hybrid model, the common factor is regressed onto the $SES \cdot age$ interaction term (a domain-general pathway), and direct effects from the interaction term to the individual outcomes (domain-specific pathways) are added where statistically significant. This is achieved by adding the direct effects one by one beginning with the effect that produces the largest increment in model fit, until addition of further direct effect do not result in statistically significant fit improvements at $p<.05$. This model produces the most parsimonious representation that is able to account for the socioeconomic differences in age trends in all 11 outcomes. A schematic of this model is represented in Fig. 1, with a predictor variable (e.g. parental education, age, or the parental education by age interaction) labeled x, the common factor (general cognitive ability) labeled F, and the individual cognition and achievement outcomes labeled y. Domain-general and domain-specific pathways are represented with dotted lines and factor loadings represented with solid lines. Note that when the domain-general pathway is removed and all domain-specific pathways are estimated, this model represents the independent pathways model. When the domain-specific pathways are removed, this model represents the common pathway model.

2. Results

Age trajectories for low (less than high school diploma), middle (high school diploma or some college), and high (bachelor's degree or higher) parental education groups are displayed in Fig. 2 for each of the eleven cognition and achievement outcomes. The age means in the figure were derived from the raw data, whereas the age curves were derived from parameter estimates from the least restrictive independent pathways model. The Y-axis has been scaled to a z metric (standard deviation = 1) based on the age-independent sample standard deviation, and centered at 0 for 18-year olds. For all outcomes, except for processing speed, parental education was associated with steeper age-related differences. Alternatively put, socioeconomic differences in cognition and achievement increased with age. In terms of the parameter estimates from the independent pathway model, the interaction term, β_2, was not statistically significant for processing speed, was significant at $p<.05$ for short-term memory and auditory processing, and was significant at $p<.01$ for the eight remaining outcomes. A complete report of parameter estimates and fit statistics for the independent pathways model is presented in the top portion of Table 3.

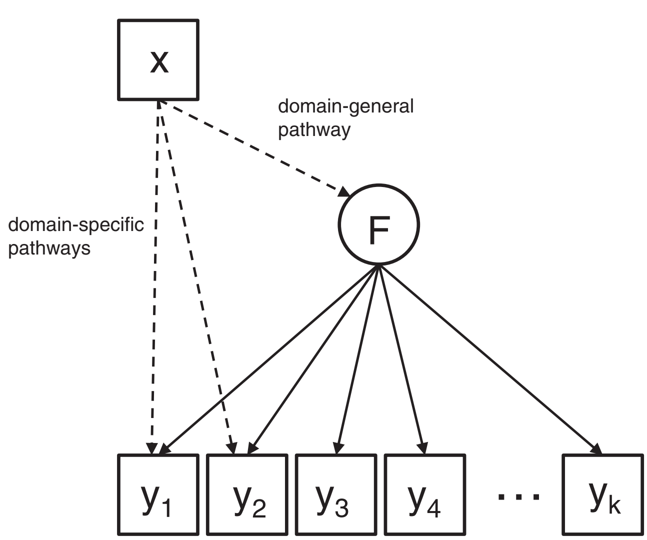

Fig. 1. A generalized representation of the modeling approach employed. Domain-general and domain-specific pathways are represented with dotted lines and factor loadings are represented with solid lines. For ease of presentation, only one domain-specific pathway is included. Note that when the domain-general pathway is removed and all domain-specific pathways are estimated, this model represents the independent pathways model. When the domain-specific pathways are removed, this model represents the common pathway model.

The first question addressed was whether the information captured by these ten statistically significant interaction terms in the independent pathways model could be just as adequately captured with the common pathway model, in which a single interaction term influenced the common factor. In other words, could the relations between parental education and age trends in the cognition and academic outcomes be attributed to differences in a single developmental process? The fit of the common pathway model suggested that they could not, as this model resulted in a statistically significant loss of information relative to the independent pathways model ($\chi^2[10] = 49$, $p<.01$).[2] A complete report of parameter estimates and fit statistics for the common pathway model is presented in the middle portion of Table 3.

Next, a common plus independent pathways model was fit. Compared to the least parsimonious independent pathways model, this more parsimonious model did not result in a statistically significant loss of information ($\chi^2[7] = 8.6$, $p = .72$), and was therefore accepted as the best representation of the data. In addition to allowing for the interaction term to act on a common pathway ($p<.01$), this model allowed for direct parental education by age interaction effects on individual outcomes where statistically significant. There were three such direct pathways: (a) a negative interaction effect on processing speed; (b) a positive interaction effect on mathematics; and (c) a positive interaction effect on academic knowledge (all interaction effects were significant at $p<.01$). The negative speed pathway suggests that age differences in speed are less related to parental education than might be expected based on its relation with the common factor, whereas the positive mathematics and academic knowledge pathways suggest that the associations between parental education and age-related differences in these achievement outcomes are attributable to supplemental mechanisms that are specific to these outcomes. For academic knowledge, the indirect interaction effect of parental education that was mediated through the common factor was .25, and the direct interaction effect of parental education was .15. For mathematics, the indirect interaction effect of parental education that was mediated through the common factor was .25, and the direct interaction effect of parental education was .24. A complete report of parameter estimates and fit statistics for the common plus independent pathways model is presented in the bottom portion of Table 3.

3. Discussion

Consistent with past research, the current project identified socioeconomic differences in many different cognitive abilities and forms of academic achievement that widened with development. To illustrate, at 5 years of age, children whose parents did not complete high school differed in abstract reasoning from children whose parents had completed college by approximately 0.50 points on a z-scale (age independent standard deviation = 1), but at 17 years of age this difference had

[2] Note that the χ^2 difference tests reported here make use of model-specific scaling coefficients. The individual model χ^2 values reported in the tables cannot be directly compared to one another to produce an accurate χ^2 difference test.

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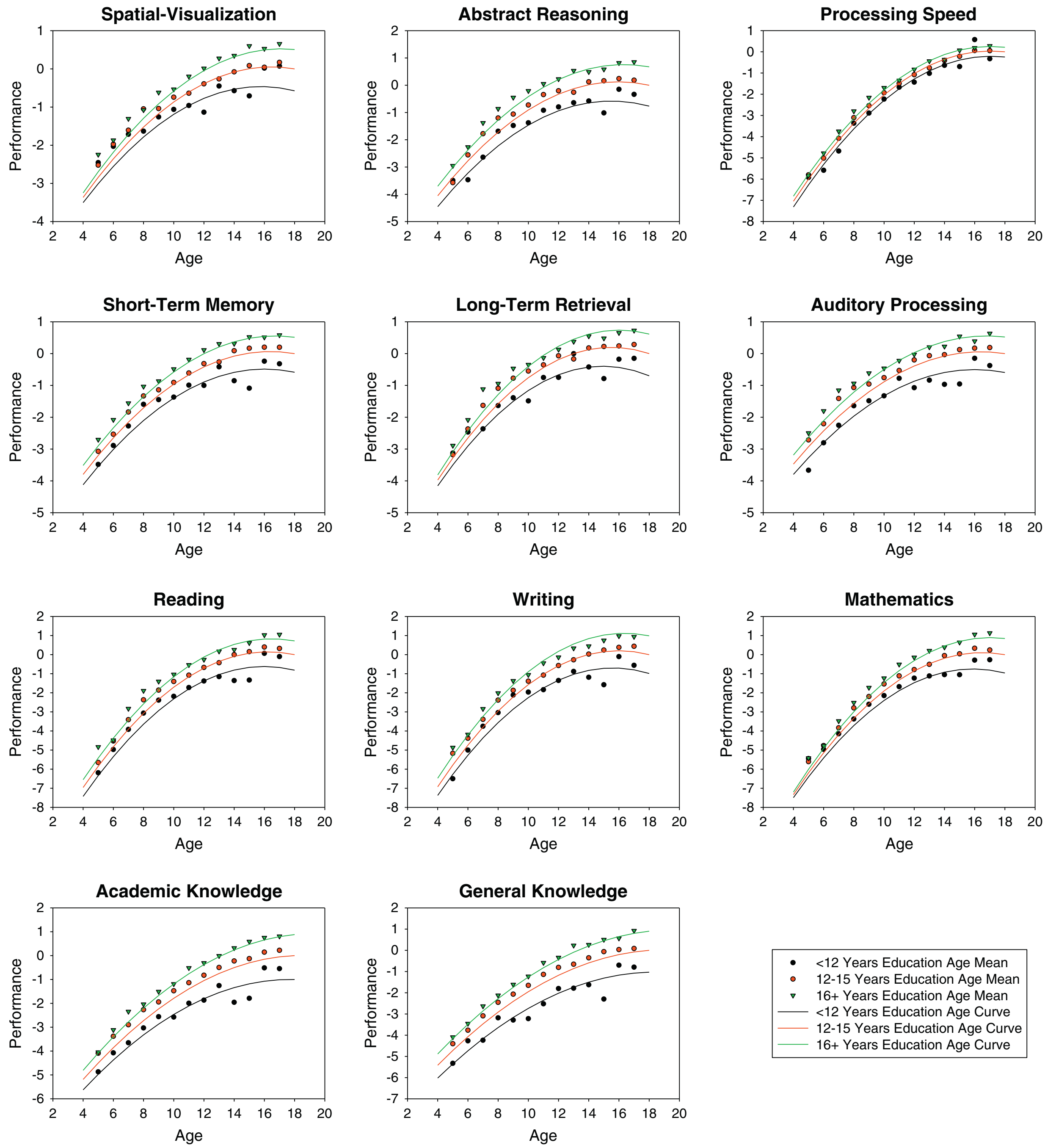

Fig. 2. Developmental trajectories in each of the eleven cognition and achievement outcomes for low (less than high school diploma), middle (high school diploma or some college), and high (bachelor's degree or higher) levels of parental education. For interpretability, the vertical axis has been converted to a *z* metric (standard deviation = 1) based on the age-independent sample standard deviation and centered at 0 for mid-SES 18 year olds. The points represent the means from the raw data. The curves are based on estimates from the independent pathways model. Data come from 4810 participants. Note that, while the figure presents results according to low, middle, and high levels of parental education, all results reported (including the age curves plotted in this figure) are based models applied to the more continuous index of parental education described in Measures section.

grown to over 1.10 points.[3] On an IQ scale (age independent standard deviation = 15), this amounts to an increase in the difference between low and high SES children from 7.5 points to 16.5 points over the course of grade school. The novel finding reported in this article is that these SES-related differences in age-related trends could be fully accounted for by a single common pathway — with two important exceptions. Socioeconomic differences in age-related trends in mathematics achievement and academic knowledge were larger in magnitude than would have been predicted by a common developmental pathway. Additional pathways were needed to account for these differences, suggesting the incremental operation of added mechanisms that are specific to these outcomes. Interestingly, age trends in processing speed did not differ by level of parental education, and hence, a third

[3] *z*-Scale (SD = 1) and IQ scale (SD = 15) are based on the age-independent sample standard deviation and centered at 0 for mid-SES 18 year olds.

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Table 3
Parameter estimates from independent pathways model, common pathway model, and common plus independent pathways model.

	Parameter estimates						
Outcome	τ	α_1	α_2	β_1	β_2	λ (λ_{std})	σ^2_u
Independent pathways model: $\chi^2=823.373$, df = 42, RMSEA = .062 [90% CI = .059–.066], CFI = .985; TLI = .966							
General Knowledge	462.647	9.707	−0.343	5.491	0.261	2.864 (.721)	75.961
Spatial-Visualization	482.617	4.664	−0.202	0.918*	0.174	1.215 (.444)	60.161
Abstract Reasoning	463.054	9.988	−0.455	3.961	0.246	3.074 (.695)	101.361
Processing Speed	433.782	17.709	−0.735	2.874	−0.021†	3.326 (.615)	181.491
Short-Term Memory	459.818	11.167	−0.489	4.000	0.219*	3.674 (.631)	204.457
Long-Term Retrieval	485.672	4.027	−0.191	0.797	0.134	1.181 (.697)	14.774
Auditory Processing	481.484	5.207	−0.227	2.053	0.115*	1.648 (.569)	56.677
Reading	405.188	25.094	−1.113	6.947	0.353	5.902 (.830)	157.798
Mathematics	442.991	15.389	−0.666	1.772	0.486	3.171 (.761)	72.994
Writing	449.290	13.548	−0.610	2.997	0.235	2.869 (.762)	59.532
Academic Knowledge	456.936	11.335	−0.416	4.846	0.413	3.103 (.652)	130.205
Common pathway model: $\chi^2=837.236$, df = 52, RMSEA = .056 [90% CI = .053–.059], CFI = .985, TLI = .972							
General Knowledge	462.661	9.708	−0.343	5.550		2.866 (.721)	75.846
Spatial-Visualization	482.629	4.651	−0.201	1.311		1.224 (.446)	60.183
Abstract Reasoning	463.063	9.985	−0.455	3.827		3.074 (.695)	101.207
Processing Speed	433.615	17.777	−0.741	1.044		3.281 (.608)	183.315
Short-Term Memory	459.752	11.192	−0.491	3.399		3.662 (.629)	204.638
Long-Term Retrieval	485.663	4.025	−0.190	0.976		1.186 (.698)	14.784
Auditory Processing	481.485	5.207	−0.228	1.883		1.644 (.568)	56.707
Reading	405.142	25.119	−1.116	5.878		5.878 (.828)	158.800
Mathematics	443.183	15.344	−0.664	3.064		3.184 (.761)	73.450
Writing	449.280	13.557	−0.610	2.892		2.864 (.761)	59.638
Academic Knowledge	456.997	11.329	−0.416	5.664		3.117 (.653)	130.361
Common Factor (*F*)					0.088		
Common plus independent pathways model: $\chi^2=797.731$, df = 49, RMSEA = .056 [90% CI = .053–.060], CFI = .986, TLI = .972							
General Knowledge	462.638	9.711	−0.343	5.667		2.866 (.721)	76.011
Spatial-Visualization	482.627	4.651	−0.201	1.365		1.224 (.446)	60.198
Abstract Reasoning	463.054	9.987	−0.455	3.960		3.074 (.695)	101.333
Processing Speed	433.773	17.712	−0.735	2.861	−0.286	3.325 (.615)	181.531
Short-Term Memory	459.755	11.191	−0.491	3.557		3.665 (.629)	204.647
Long-Term Retrieval	485.660	4.026	−0.190	1.028		1.187 (.699)	14.775
Auditory Processing	481.487	5.207	−0.227	1.956		1.645 (.568)	56.696
Reading	405.065	25.138	−1.117	6.144		5.891 (.829)	158.235
Mathematics	442.961	15.399	−0.667	1.730	0.238	3.172 (.761)	72.966
Writing	449.267	13.559	−0.610	3.023		2.869 (.762)	59.547
Academic Knowledge	456.932	11.338	−0.416	4.949	0.147	3.105 (.652)	130.182
Common Factor (*F*)					0.080		

Note: The fit of the individual model is provided following the name of the each model. Age was centered at 5 prior to analyses. Education was centered at its mean prior to analyses. In order to avoid estimation difficulties associated with large unstandardized factor loadings, the common factor was scaled to have a variance of 10. τ = regression intercept. α_1 = coefficient on *age*. α_2 = coefficient on *age*^{2}. β_1 = coefficient on parental education. β_2 = coefficient on interaction between age and parental education. λ = unstandardized factor loading. λ_{std} = standardized factor loading. σ^2_u = residual variance. RMSEA = room mean square error of approximation. CFI = comparative fit index. TLI = Tucker Lewis index. The individual model χ^2 values reported in this cannot be directly compared to one another to produce an accurate χ^2 difference test. The χ^2 difference tests reported in the text use model-specific scaling coefficients in order to make correct comparisons. All parameters significant at p < .01, except where otherwise noted.
* p < .05.
† p > .05.

independent pathway was needed to correct for the disparities in processing speed that would have otherwise been expected based on disparities in general cognitive development.

3.1. Interpreting the pathways

The current findings indicate both domain-general and domain-specific pathways by which parental education relates to age trends in a diverse set of cognitive abilities and academic achievement domains. How should these findings be interpreted? One key point to emphasize is that the factors extracted and pathways identified represented statistical dimensions of variation and covariation. Importantly, a single statistical dimension need not represent a single social process, biological process, or cognitive mechanism. For example, it has been discussed at length in the literature that general cognitive ability may not represent a single biological or psychological entity (Carroll, 1993; Gould, 1996; Tucker-Drob, 2011; Van Der Maas et al., 2006). Rather, general cognitive ability may be affected by many thousands of genes (Davies et al., 2011) and environments (Turkheimer, 2000), each with small, albeit generalized effects, and may be undergirded by multiple neurophysiological structures and cognitive processes (Colom, Jung, & Haier, 2006; Kovas & Plomin, 2006) Moreover, the domain-general and domain-specific pathways identified need not represent a single process; each pathway may represent a constellation of processes that covary with parental education (and hence with one another) and have similar effects on the domain(s) in question. For instance, if availability of books in the home and parental help with homework both covary with parental education and have incremental relations with the development of academic knowledge above and beyond relations with the development of general cognitive ability, then they may both underlie the domain-specific pathway between parental education and academic knowledge. Identifying the intermediary mechanisms between parental educational attainment and both domain-general and domain-specific aspects of cognitive development will necessitate detailed multivariate measurement of the social, biological, and experiential factors that covary with both parental education and cognitive development, along with similarly detailed multivariate measurement of cognitive abilities.

The three individual domain-specific pathways identified are themselves noteworthy. SES was related to age trends in mathematics achievement and academic knowledge incremental to its association with age-related gains in general cognitive ability. This indicates that children from low SES backgrounds come to be at an even greater disadvantage in achievement domains than they would be expected to be at based on their disadvantage in general cognitive ability. One possible explanation for this finding is that SES-related inequalities in the educational system have incremental effects on academic skills above and beyond more generalized cognitive disparities associated with family resources (cf. Ceci, 1991). Moreover, that age trends in processing speed did not differ by level of parental education may indicate that processing speed is an ability that is particularly robust to environmental influence, as a number of researchers have previously suggested (e.g. Nettelbeck & Wilson, 2004).

3.2. Implications

The current results have both theoretical and practical implications for cognitive development research. On the theoretical side, these results make clear that socioeconomic status does not simply relate to the development of a few specialized types of knowledge or skill, but rather, relates to the development of manifold domains of cognitive functioning and academic achievement, ranging from simple recall of information to complex reasoning skills and mathematical proficiency. Moreover, these relations appear to be largely – although, in the case of mathematics and academic knowledge, not entirely – mediated by a more proximal relation between socioeconomic status and the development of a very general dimension of cognitive functioning that is common to many specific cognition and achievement domains. On the practical side, these findings present a challenge to standard interpretations of the simple bivariate relations that are often observed between socioeconomic status and a single cognition or achievement outcome. That is, while it may be tempting to interpret such bivariate relations as indication that a circumscribed domain-specific mechanism is at work, it is likely to be the case that the observed relation is, at least in part, a manifestation of differences in a very broad dimension of functioning that requires a domain-general explanation. Multivariate approaches can help to overcome this challenge by allowing researchers to take into account the codependence that multiple outcomes have with one another so that they can meaningfully examine the incremental effects of socioeconomic measures on individual outcomes.

The implications of the current results for applied interventions are less clear. This was a descriptive study that did not involve experimental manipulation. The findings do, however, raise interesting questions about ways to structure interventions. For example, the finding that the majority of SES-related differences in age trends in multiple abilities occurred via a domain-general pathway indicates that it might be fruitful to investigate whether interventions for impoverished children that target very generalized processes can have far-reaching effects on cognitive development. If this were the case, it would obviate the need to directly target every specific ability on which a deficit was observed. However, based on recent dynamical systems theories cognitive development (Dickens, 2007; Van Der Maas et al., 2006), it is also possible that transfer of domain-specific training could occur, in which tutoring specific skills could have far reaching effects beyond the specific skills tutored. Randomized intervention research taking these different approaches is necessary to test these possibilities. Of course, ameliorative interventions for social class differences in cognitive development need not target the mechanisms that are the original sources of those differences. Interventions can also be compensatory, by targeting different mechanisms than those affected and/or training children to rely more heavily on different skills and abilities (cf. Baltes, 1997).

3.3. Limitations

The current findings are particularly informative about the broad patterns by which socioeconomic differences in cognition and achievement emerge over the school years. Nevertheless, because data on very early childhood were not available, the current results only apply to development that occurs during the school years, and not to development that occurs prior to school entry. There is substantial evidence that socioeconomic differences in cognitive development and school readiness begin to arise during the first five years of life (Heckman, 2006; Tucker-Drob, 2012; Tucker-Drob, Rhemtulla, Harden, Turkheimer, & Fask, 2011). During infancy, children are primarily confined to their home environments, whereas during the school years, substantial portions of children's experiences occur outside of the home. As such, the patterns by which socioeconomic differences are manifest during infancy have the potential to be quite different from those by which they are manifest during the school years.

A second limitation is that the current study was based on cross-sectional, rather than longitudinal, data. Unfortunately, the nationally representative longitudinal datasets that do exist on child cognitive development and academic achievement (e.g. the Early Childhood Longitudinal Studies conducted by the US Department of Education) only include measures on a small set of cognition and achievement domains, the domains are only measured using brief tests, and not all domains are represented in each wave of assessment. In contrast, the nationally representative WJ-III dataset analyzed here includes measures of 11 domains of cognition and achievement, each domain is measured using up to three highly sensitive individual tests, and all 11 domains are measured for participants between ages 5 and 18. Therefore, while longitudinal data would have been ideal for testing the hypotheses in question, there do not appear to be longitudinal data available of comparable quality to the cross-sectional data analyzed here.

3.4. Future directions

An overarching goal of research on socioeconomic differences in cognitive development will continue to be to identify the developmental mechanisms that give rise to these differences. This is a particularly important area of ongoing research in light of recent evidence implicating cognitive abilities and academic achievement as "fundamental" mediators of socioeconomic differences in multiple social, economic, and health outcomes, including better wages and employment, lower teenage pregnancy, less smoking, lower law-breaking, and greater overall health, longevity, and subjective well-being (Cunha & Heckman, 2009; Deary, 2008; Goldman & Smith, 2002; Gottfredson, 2004; Sackett, Kuncel, Arneson, Cooper, & Waters, 2009). In other words, children raised in low SES homes are at elevated risks for multiple adverse life outcomes in part because of lower cognitive ability and lower school achievement. The goal of the current study was not to identify specific mechanisms underlying the SES–cognition relation, but rather, to clarify the developmental patterns that will eventually need to be explained. Results suggest that two sets of mechanisms will prove important: those that underlie socioeconomic differences in general cognitive development, and those that incrementally underlie socioeconomic differences in specific academic domains — academic knowledge and mathematics in particular. What forms might such mechanisms might take? As discussed earlier, mechanisms underlying the SES–cognition relation can be generally classified as either social selection mechanisms or social causation mechanisms (Huston & Bentley, 2010). Both mechanisms are likely to contribute to the differences observed to some extent. For instance, there is strong evidence from adoption studies that, genes for

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general cognitive ability and academic achievement are genetically transmitted from parents to their biological offspring, and that being raised in a more privileged home has a substantial causal effect on cognitive development (Capron & Duyme, 1989; Nelson et al., 2007; Plug & Vijverberg, 2003). However, as many have previously argued (e.g. Ceci, 1996; Harden, Turkheimer, & Loehlin, 2007; Rhemtulla & Tucker-Drob, 2012; Scarr-Salapatek, 1971; Tucker-Drob et al., 2011; Turkheimer, Haley, Waldron, D'Onofrio, & Gottesman, 2003), even the realization of genetic potentials is likely to rely on the adequacy of experiential inputs. Aspects of the environment that are routinely linked with SES and have been suggested to play key roles in cognitive development and academic achievement include availability of educational materials (Bradley & Corwyn, 2002), parental allocation of time spent with their children (Guryan, Hurst, & Kearney, 2008; Kalil, Ryan, & Corey, 2010), and school and teacher quality (Kazdin, Kraemer, Kessler, Kupfer, & Offord, 1997; Nisbett, 2009; Taylor, Roehrig, Soden Hensler, Connor, & Schatschneider, 2010), to name a few.

4. Conclusions

In summary, parental education was found to relate to age trends in multiple diverse forms of cognition and achievement throughout the school years. The differences were entirely mediated by a general dimension of cognition function for all but two domains: mathematics and academic knowledge. For these domains, additional direct pathways were needed to account for widening socioeconomic differences with age. These results suggest that while socioeconomic differences are largely manifested in global aspects of cognitive development, they have incremental relations with some forms of academic achievement. These results help to delineate the specific developmental patterns that will eventually need to be accounted for by explanatory theories of social inequality.

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Appendix A. Distributions of age and parental education

Table A1
Distribution of age.

Age (years)	Proportion of sample
4 and below	1.4%
5.00	4.6%
6.00	6.3%
7.00	7.0%
8.00	8.5%
9.00	10.3%
10.00	11.3%
11.00	8.5%
12.00	7.2%
13.00	6.7%
14.00	6.0%
15.00	6.3%
16.00	6.4%
17.00	4.8%
18 and above	3.3%

Table A2
Distribution of parental educational attainment (mean of maternal and paternal educational attainment).

Education category	Proportion of sample
1.00 (less than 5th grade)	.7%
1.50	.4%
2.00 (less than high school diploma)	4.7%
2.50	6.5%
3.00 (high school graduate)	22.2%
3.50	15.8%
4.00 (some college)	18.8%
4.50	11.4%
5.00 (bachelors degree and above)	19.5%

Note. Educational attainment was measured for each parent on a 1–5 integer scale. However, because educational attainment for mothers and fathers was averaged for the purposes for the current paper, educational attainment took on half-point values as well.

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