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What is This?
Short Report

Longitudinal Evidence That Increases in Processing Speed and Working Memory Enhance Children’s Reasoning

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As children develop, their information-processing speed (PS) increases, and they retain more information in working memory (WM); these changes have been hypothesized to drive age-related improvements in reasoning and problem solving. For example, in Fry and Hale’s (1996) cascade model, developmental change in PS increases the functional capacity of WM, which in turn facilitates reasoning. Studies have shown that developmental increases in PS and WM during childhood and adolescence predict developmental improvements in inductive reasoning (Fry & Hale, 1996) and in accuracy on arithmetic word problems (Kail & Hall, 1999). However, although these findings are consistent with the cascade model, they provide relatively weak support because they are based on concurrent correlations derived from cross-sectional studies. The present work was designed to provide a stronger test of the cascade model using longitudinal evidence.

METHOD

Participating were one hundred eighty-five 8- to 13-year-olds ($M = 10.35$ years, $SD = 1.44$; 90 girls) recruited via newspaper articles and letters to university alumni. Initially (Time 1), they completed two measures of PS. In the Visual Matching task, each of 60 rows included six digits, two of which were identical; participants circled the identical digits. In the Cross Out task, each of 30 rows consisted of a geometric figure at the left end and 19 similar figures to the right; participants placed a line through the 5 figures of the 19 that matched the figure at the left. For both tasks, the score was the number of rows completed correctly in 3 min.

Children also completed two WM tasks (from Daneman & Carpenter, 1980). Reading span was measured using brief sentences (each printed on a card) that ended in a noun and made assertions that were obviously true or false. Children read a sentence aloud, indicated whether or not it was true, read the sentence on the next card, and so on. After the final sentence in a set, they recalled the nouns in order. Testing began with two 1-sentence sets, progressed to two 2-sentence sets if recall was accurate, and continued until the child failed to recall the nouns in a set accurately or completed two 5-sentence sets. The listening-span task was analogous, but sentences were presented via audiotape. Span was defined as the number of words recalled in order.

Inductive reasoning was measured using 30 odd-numbered problems from Raven’s (1958) Standard Progressive Matrices. Testing continued until children completed all 30 problems or erred on 4 consecutive problems.

The five tasks were presented in a constant order: Cross Out, Raven’s, listening span, Visual Matching, and reading span. One year later (Time 2), the children were retested on 30 even-numbered problems from Raven’s Standard Progressive Matrices.

RESULTS AND DISCUSSION

Of the 185 children tested initially, 162 were retested, and 160 provided complete data. The 160 children with complete data did not differ significantly from the other 25 children on any measure. Performance at Time 1 improved with age: Correlations between age and performance ranged from .34 (listening span) to .68 (Visual Matching), all $p_{rep} > .99$. Scores on the two PS tasks were related, as were scores on the two WM tasks, $rs = .81$ and .48, respectively, $p_{rep} > .99$. In addition, performance
on the PS and WM tasks was related to Raven’s scores at Time 1 (range: .33 for listening span to .50 for Cross Out, all $p_{rep} > .99$).

The cascade model was evaluated with structural equation modeling. The fit of individual models was evaluated with two measures. The adjusted goodness-of-fit index (AGFI) measures the correspondence of the observed covariance matrix with that predicted by the model; values greater than .90 indicate adequate fit. The root mean square error of approximation (RMSEA) measures the size of the residuals; values less than .10 indicate adequate fit. Nested models were compared by computing the difference in chi-square values of the models.

Modeling began with the Time 1 data. The initial model included six paths: from age to PS (estimated by Visual Matching and Cross Out), WM (estimated by reading and listening span), and reasoning (represented by Raven’s scores); from PS to WM and reasoning; and from WM to reasoning. The fit of this model was nearly adequate, $AGFI = .885$, $RMSEA = .105$, but coefficients for three paths (age to WM, age to reasoning, and PS to reasoning) were not significant. A reduced model without those paths fit the data equally well, $\chi^2(3) = 2.80$, $p > .05$, $AGFI = .917$, $RMSEA = .083$. Notably, the remaining paths—from age to PS to WM to reasoning—define the cascade model.

The critical test involved longitudinal prediction of reasoning scores at Time 2. The first longitudinal model included paths from the reduced model of Time 1 data, along with paths linking PS, WM, and reasoning at Time 1 to reasoning at Time 2. The fit was adequate, $AGFI = .908$, $RMSEA = .079$. However, the path from PS to reasoning at Time 2 was not significant; a model without this path fit the data equally well, $\chi^2(1) = 2.77$, $p > .05$, $AGFI = .905$, $RMSEA = .082$.

The final model, shown in Figure 1, links developmental change in PS to greater WM capacity, which is associated with better inductive reasoning. This pattern is evident cross-sectionally, replicating the findings of Fry and Hale (1996). More important, the pattern is also evident longitudinally, which provides stronger evidence for a causal chain in which WM affects developmental change in inductive reasoning directly and PS does so indirectly. Of course, the cascade model is limited in focusing on analytic decision-making processes rather than experiential processes (Klaczynski, 2004), in ignoring the contribution of problem-relevant knowledge to children’s reasoning (Goswami, 2002), and in failing to identify the specific processes by which PS and WM facilitate reasoning (cf. Cowan et al., 2006). Nevertheless, it is clear that increased PS and WM capacity represent one factor driving developmental change in inductive reasoning.

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