Abstract Title Page
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Title: Why do Fine Motor Skills Predict Mathematics? Construct Validity of the Design Copying Task

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Abstract Body

Limit 4 pages single-spaced.

Background / Context:

Description of prior research and its intellectual context.

Recent educational studies have found evidence that measures of fine motor skills are predictive of educational outcomes. However, the precise nature of fine motor skills has received little attention in these studies. The design copying task has emerged as an important task thought to measure fine motor skills in the education literature (Cameron et al., 2012). However, there is a disconnect between cognitive science and educational science as to which construct best explain performance on design copying tasks. While within the education literature, design copying is considered a measure of fine motor skills, in the cognitive sciences, design copying is considered primarily a measure of visuospatial skills or visuomotor integration. With evidence mounting that fine motor skills are an important indicator of school readiness, investigating the nature of this measure and explaining its association with achievement is a key priority for researchers (Cameron et al., 2012).

Purpose / Objective / Research Question / Focus of Study:

Description of the focus of the research.

This interdisciplinary study uses theory and measures from neuropsychology to decompose the association between the design copying task and mathematics achievement into fundamental component cognitive processes. The primary aim was to examine the construct validity of design copying as a predictor of mathematics achievement. This study was developed to answer three research questions:

1. Using robust direct measures of cognitive processes, can we replicate the association between design copying and mathematics achievement found in previous studies?

2. How well do the component processes from the visuospatial, sensorimotor, and EF domains together explain this association?

3. Which specific component processes are helpful in explaining the association between design copying and mathematics achievement?

Setting:

Description of the research location.

To answer the research questions, baseline data from the pilot data of the Minds In Motion Intervention were used. The pilot study took place in several elementary after-school programs located in two demographically different counties in the same Mid-Atlantic state (one in a light farming region and the other in a suburban region). All after-school programs were fee-based but offered a sliding scale.

Population / Participants / Subjects:

Description of the participants in the study: who, how many, key features, or characteristics.

Participants included 145 Kindergarten, first, and second grade students enrolled in school-based after-school programs. The children ranged in age from 5 years 3 months to 8 years 3 months.

The sample was evenly divided across gender, with 73 boys (50.3%) and 72 girls (49.7%). The majority of children were Caucasian/White (55.2%, n = 80). Other races/ethnicities represented in the sample were African American/Black (n = 31, 21.4%), Asian (n = 5, 3.4%), Hispanic (n = 1, .7%), more than one race (n = 27, 18.6%), and other (n = 1, .7%).

Research Design:
Description of the research design.

Mediation analysis has previously been used in the literature as a method to evaluate construct validity (e.g., Baer, et al., 2008, Satz, Cole, Hardy, & Rassovsky, 2011). Thus we adopted a multiple mediation model to simultaneously evaluate the contribution of each of the proposed component cognitive processes to the association between design copying and mathematics achievement (Preacher & Hayes, 2008). To answer the first research question, we determined whether the expected association between design copying and mathematics achievement was observed in the study sample, while controlling for children's age, race, and gender. To answer the second research question, we determined the extent to which measures of visuospatial processing, sensorimotor processing, and EF, taken together, mediated this association. To answer the final research question, we explored whether specific measures from each of the three domains mediated the relation between design copying and mathematics, while controlling for the other component processes as well as age, race, and gender.

Data Collection and Analysis:
Description of the methods for collecting and analyzing data.

Families were recruited into the study in November and December of 2009 and completed a 13-item family questionnaire. This questionnaire included demographic information such as gender, race, and the child's age, which were used as covariates in the analysis. In January and February of 2010, participants completed a set of direct assessments, individually administered by trained research personnel (e.g., graduate students, undergraduate research assistants, and teachers). These were conducted in a quiet area of the child's school or classroom. The entire battery lasted approximately 45-60 minutes and involved measures of cognitive functioning and academic achievement.

Relevant subtests of the NEPSY (Korkman et al., 1998) served as a direct measure of children's cognitive processes. The NEPSY is a comprehensive neuropsychological assessment battery for children aged 3-12 years. Subtests from the NEPSY included those from three cognitive domains. EF subscales used specifically target both auditory and visual discrimination and focus, as well as cognitive set shifting, and include Visual Attention, Auditory Attention and Response Set, and Tower. Subtest from the visuospatial domain include Arrows and design copying. Subscales from the sensorimotor domain include Fingertip Tapping, Imitating Hand Positions, and Visuomotor Precision.
The Basic Concepts composite of the Key Math 3 (Connolly, 2007), a comprehensive mathematics assessment for children aged 4½ through 21, served as the direct measure of mathematics achievement. The Basic Concepts composite includes procedural and computational skills associated with the first five subtests of the battery. Questions and responses are presented verbally, with most questions also having a visual component (e.g., pictured objects, charts).

The five subtests that comprise the Basic Concepts Domain of the Key Math 3 include Numeration, Algebra, Geometry, Measurement, and Data Analysis and Probability. Numeration measures early number awareness and number sense, measuring skills such as representing, comparing and rounding one-, two-, and three-digit numbers; fractions; decimals; percentages; and place value. Algebra measures pre-algebraic and algebraic concepts such as sorting, recognizing patterns, number sentences, variables, and proportions. Geometry involves early geometric awareness as well as recognition and comparison of two- and three-dimensional shapes. Specific topics covered include spatial relationships, coordinates, symmetry, angle comparisons, and parallel and intersecting lines. Measurement involves using standard units, time, and money to solve problems. Questions cover topics that involve sequencing, estimation, length and distance measurement, and volume calculation. Data Analysis and Probability measures the ability to collect, display, and interpret data, as well as understand concepts of chance and probability. Specific skills include reading tables, interpreting charts, and estimating amount.

The amount of missing data in the sample was small, with only 2.1% of all data points missing. The percent missing for each variable used in the model ranged from 0 to 5.5%. There was only one case that was missing the dependent variable. To use all available information in the data, Full Information Maximum Likelihood Estimation (FIML) in Mplus version 6.1 (Muthen & Muthen, 2010) was used for all analyses. To explore which of the component processes help explain the association between the design copying task and mathematics achievement, we analyzed the data using a multiple mediation model within a path analysis framework, with design copying as the predictor, mathematics achievement as the outcome, and the other NEPSY subscales as the multiple mediators (See Figure 1). Confidence intervals were generated using 5,000 iterations of bias corrected bootstrapping and are reported at the 95% level.

Findings / Results:
Description of the main findings with specific details.

Three findings are evident from this study. First, our results establish a strong direct association between design copying and mathematics achievement ($r = .71$), a relation suggested by previous research associating fine motor skills with academic achievement. This association was evident after controlling of age, race, and gender. The total effect between design copying and mathematic achievement was .50 with a CI of .34 to .67 (See Table 1). Second, the association between design copying and mathematics achievement is partially mediated by multiple cognitive component processes. The estimate of the sum of the indirect effects was .22, with a CI of .12 to .34. Important mediators included two of the three executive functioning measures (Tower and Auditory Attention), the visuospatial processing subscale (Arrows), and one sensorimotor processing subscale (Imitating Hands, see table 1). It should be noted, however, that among sensorimotor processes, fine graphomotor skills and finger dexterity, as measured by Visuomotor Precision and Fingertip Tapping tasks respectively, were not found to mediate the association, suggesting that EF and visuospatial skills might be more important in explaining the association between design copying and mathematics achievement than fine motor skills. Third, because the model only partially explains the association between design copying and mathematics, other underlying cognitive processes that were not examined in this study need to be explored as additional constructs important for explaining this association.

Conclusions:

Description of conclusions, recommendations, and limitations based on findings.

The most parsimonious interpretation of our results, taken as a whole, is that the association between children's performance on the design copying task and their mathematics achievement can be attributed to a common dependence on visuospatial skills, EF, and possibly other cognitive component processes yet to be identified. Although our results and measures are complex, the most significant finding is straightforward: children who are better at design copying tasks are better at mathematics. Furthermore, this has more to do with their ability to process visuospatial information and less to do with their skill at holding and manipulating a pencil. By linking these cognitive processes to mathematics achievement, studies like this help build a natural bridge between cognitive science, and education. Such studies are important for moving education science beyond identifying which skills are predictive of school readiness to understanding why these skills are important.

Appendices

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Appendix A. References

References are to be in APA version 6 format.

Baer, R. A., Smith, G. T., Lykins, E., Button, D., Krietemeyer, J., Sauer, S., … Williams, J. M. G. (2008). Construct validity of the five facet mindfulness questionnaire in meditating and nonmeditating samples. *Assessment*, *15*(3), 329–342.

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Satz, P., Cole, M. A., Hardy, D. J., & Rassovsky, Y. (2011). Brain and cognitive reserve: Mediator (s) and construct validity, a critique. *Journal of Clinical and Experimental Neuropsychology*, *33*(1), 121–130.

Appendix B. Tables and Figures
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Table 1.
Multiple Mediation Model Effects

Model Effects	Coef. [b]	BC 95% CI [a]	
		Lower	Higher
Design Copy (Total Effect)	0.50*	0.34	0.67
Design Copy (Direct Effect)	0.28*	0.11	0.45
Sum of Indirect Effects	0.22*	0.12	0.34
Specific Indirect Effects			
Arrows	0.08*	0.02	0.15
Tower	0.03*	0.01	0.08
Auditory Attention	0.05*	0.01	0.11
Visual Attention	0.02	0.00	0.06
Motor Precision	0.00	-0.04	0.04
Finger Tapping	-0.02	-0.08	0.01
Imitating Hands	0.07*	0.03	0.14

[a] BC 95% CI = 95% confidence interval using bias corrected bootstrapping.
[b] Coef. = coefficient;
* $p < .05$.

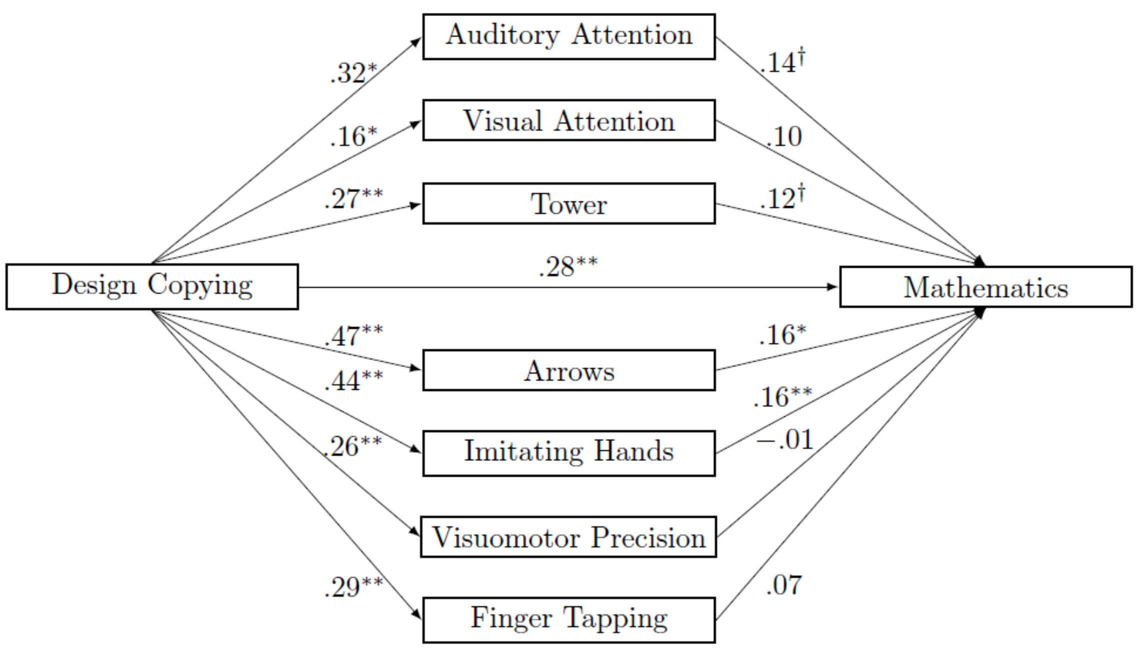

Figure 1. A multiple mediation model of design copying and mathematics achievement mediated by seven component processes from three cognitive domains: EF, visuospatial, and sensorimotor. The path coefficients for standardized variables are presented. †< .10. *<.05. **<.01.