Task Complexity as a Determinant of Mental Rotation: Gender Differences in Primary School Students

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Introduction

Mental Rotation in Early Education

- Spatial ability, especially mental rotation, is key to math learning and cognitive development

  (Cheng & Mix, 2014)

- As one of the most studied cognitive skills, it strongly correlates with mathematical success

  (Uttal et al., 2013)

- Yet, research mainly targets older learners; little is known about 6-to-10-year-olds

  (Hawes et al., 2015; Hoyek et al., 2012)

- Despite similar intelligence, gender differences in spatial ability often favor boys and appear around age 10

  (Jansen et al., 2013; Linn & Petersen, 1985)

Introduction: Aim and Research Questions

Pädagogische Hochschule Freiburg

Aim

This study examines early gender differences and effects of task complexity using a newly developed mental rotation test for primary students.

Research Questions

1. How do age and gender influence the number of tasks completed by primary school students?
2. How do item characteristics, i.e., rotation angle & stimulus complexity, affect solution probability?
3. How do gender and item characteristics interact to impact performance in mental rotation tasks?

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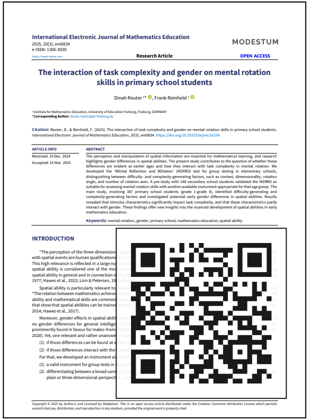
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The interaction of task complexity and gender on mental rotation skills in primary school students

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ABSTRACT
The perception and manipulation of spatial information are essential for mathematical learning, and research highlights gender differences in spatial abilities. The present study contributes to the question of whether these differences are evident at earlier ages and how they interact with task complexity in mental rotation. We developed the 'MEntal Reflection and ROtation' (MERRO) test for group testing in elementary schools, distinguishing between difficulty- and complexity-generating factors, such as context, dimensionality, rotation angle, and number of rotation axes. A pre-study with 148 secondary school students validated the MERRO as suitable for assessing mental rotation skills with another available instrument appropriate for that age group. The main study, involving 387 primary school students (grade 1-grade 4), identified difficulty-generating and complexity-generating factors and investigated potential early gender differences in spatial abilities. Results revealed that stimulus characteristics significantly impact task complexity, and that these characteristics partly interact with gender. These findings offer new insights into the nuanced development of spatial abilities in early mathematics education.

Keywords: mental rotation, gender, primary school, mathematics education, spatial ability

INTRODUCTION

Reuter & Reinhold, (2025).
Int. Elect. J. Math. Ed.

Method: The MERRO Itemset

Can you rotate the first image so that it looks the same as the second image?


☒ Yes ☐ No


☐ Yes ☒ No

Assessing students' ability to decide whether the stimuli were (a) only rotated in the paper plain, or (b) mirrored on the *y*-axis and then rotated in the paper plain.

Rotation around 45, 90, and 135 degrees.

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Context	Plain	In perspective: Not tilted	In perspective: Tilted
Context 0: Authentic pictures	 Stimulus 021  Stimulus 209  Stimulus 307  Stimulus 308		
Context 1: Cube images with one or two bends	 Stimulus 301  Stimulus 302		
Context 2: Cube images with three bends	 Stimulus 303  Stimulus 304		
Context 3: Cube images with three twisted bends			

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	 Stimulus 302	 Stimulus 402	

Context	Plain	In perspective: Not tilted	In perspective: Tilted
Context 2: Cube images with three bends	 Stimulus 303	 Stimulus 403	
	 Stimulus 304	 Stimulus 404	
Context 3: Cube images with three twisted bends		 Stimulus 405	
		 Stimulus 406	

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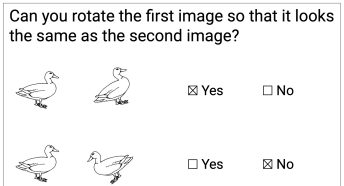
	 Stimulus 307	 Stimulus 407	 Stimulus 507
	 Stimulus 308	Stimulus 408	 Stimulus 508
Context 1: Cube images with one or two bends	 Stimulus 301	 Stimulus 401	 Stimulus 501
	 Stimulus 302	 Stimulus 402	 Stimulus 502

Context	Plain	In perspective: Not tilted	In perspective: Tilted
Context 2: Cube images with three bends	 Stimulus 303	 Stimulus 403	 Stimulus 503
	 Stimulus 304	 Stimulus 404	 Stimulus 504
Context 3: Cube images with three twisted bends		 Stimulus 405	 Stimulus 505
		 Stimulus 406	 Stimulus 506

Method: The MERRO Itemset



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Context 3: Cube images with three twisted bends		Stimulus 405	Stimulus 505
		Stimulus 406	Stimulus 506

10 Figures, 24 Stimuli, 48 Items; Cronbach's $\alpha = 0.84$ on $N = 387$.

Method: Sample & Procedure

Sample

387 primary school students—nested in $k = 24$ classrooms

Grade	*1*	*2*	*3*	*4*
Male	79	38	45	38
Female	80	26	49	32
Total	159	64	94	70

Procedure

Cross-sectional paper-based assessment: items displayed in randomized but identical order; 4 minutes time restriction

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Piloting

- Qualitative Pilot with $N = 4$: close observation & informal interviews
- Quantitative Pilot I with $N = 33$: item revision based on stimulus issues
- Quantitative Pilot II with $N = 13$: first retest reliability estimate
- Quantitative Pilot III with $N = 148$: estimation of MRT correlation in sample of older secondary students; ceiling effect in MERRO; $r(146) = 0.419^{***}$

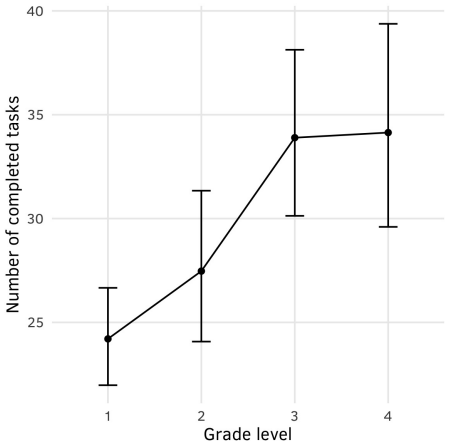
  (Mental Rotation Test, MRT, see Peters et al., 1995)

Results: Number of Completed Tasks

Fixed effects	Model 0			
	IRR	SE	95% CI	
			LL	UL
Intercept	28.597	1.245	26.258	31.144
Grade level[a]				
Gender[b]				
× Grade level				
Random effects	**Variance**	**SD**		
Classroom	0.043	0.207		
Model fit	**AIC**	**BIC**	**R^2 (m)**	**R^2 (c)**
	3,567.3	3,575.2	0.000	0.556

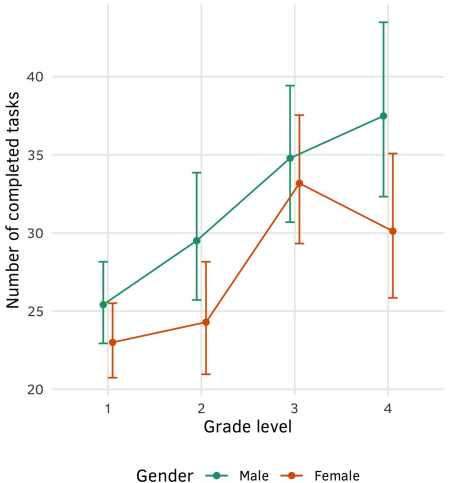
Results: Number of Completed Tasks

Fixed effects	Model 1			
	IRR	SE	95% CI	
			LL	UL
Intercept	24.431	1.130	22.313	26.750
Grade level[a]	1.140	0.032	1.079	1.204
Gender[b]				
× Grade level				
Random effects	**Variance**	**SD**		
Classroom	0.021	0.145		
Model fit	**AIC**	**BIC**	**R^2 (m)**	**R^2 (c)**
	3,553.7	3,565.5	0.293	0.562

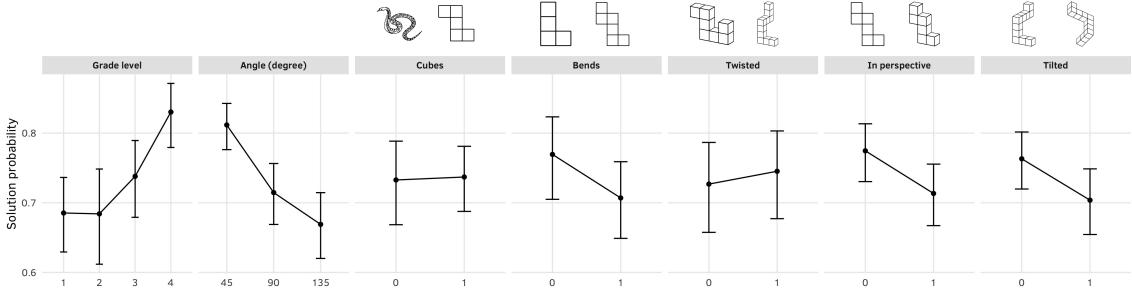


Results: Number of Completed Tasks

Fixed effects	Model 2			
	IRR	SE	95% CI	
			LL	UL
Intercept	25.577	1.257	23.229	28.162
Grade level[a]	1.150	0.034	1.086	1.219
Gender[b]	0.907	0.027	0.856	0.961
× Grade level	0.981	0.016	0.949	1.013
Random effects	**Variance**	**SD**		
Classroom	0.022	0.149		
Model fit	**AIC**	**BIC**	**R^2 (m)**	**R^2 (c)**
	3,514.8	3534.6	0.323	0.588



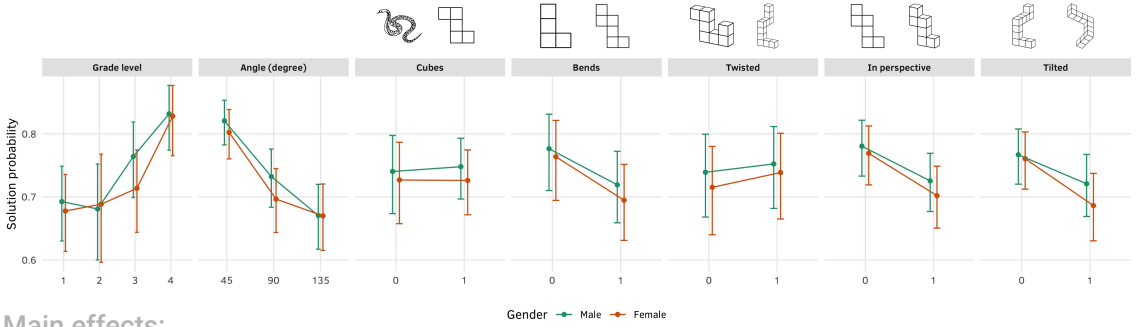
Results: Task Complexity



Main effects:

Grade level	Angle (degree)	Cubes	Bends	Twisted	In perspective	Tilted
OR = 1.282 [1.123, 1.463]	OR = 0.667 [0.614, 0.724]	OR = 1.037 [0.711, 1.511]	OR = 0.738 [0.469, 1.161]	OR = 1.072 [0.627, 1.835]	OR = 0.756 [0.600, 0.953]	OR = 0.776 [0.612, 0.984]

Results: Task Complexity



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Interactions with gender:

Grade level	Angle (degree)	Cubes	Bends	Twisted	In perspective	Tilted
OR = 0.970 [0.845, 1.114]	OR = 1.069 [0.956, 1.195]	OR = 0.954 [0.787, 1.157]	OR = 0.955 [0.765, 1.193]	OR = 1.049 [0.795, 1.384]	OR = 0.971 [0.796, 1.183]	OR = 0.866 [0.697, 1.075]

Discussion

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Early Gender Differences in Mental Rotation Skills

- Descriptive data suggest early gender differences in mental rotation in primary school.
  - Patterns resemble findings reported for older students.
  - Boys tended to solve complex 3D tasks faster and with higher accuracy than girls.
  - Boys may rely on holistic strategies; girls possibly more analytical, step-by-step.
- The MERRO test may assist in identifying students who need targeted support.
  - Strategy differences might contribute to observed performance gaps.
  - Supporting spatial skills early—especially for girls—could help address disparities.

Limitations

- Usage of older teenage sample (showing ceiling effects) to validate the MERRO.
- Observations show tendencies for the complex tilted items to be rotated in 3D.

Thank you for your attention.

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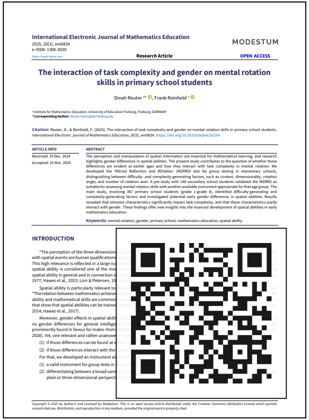

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