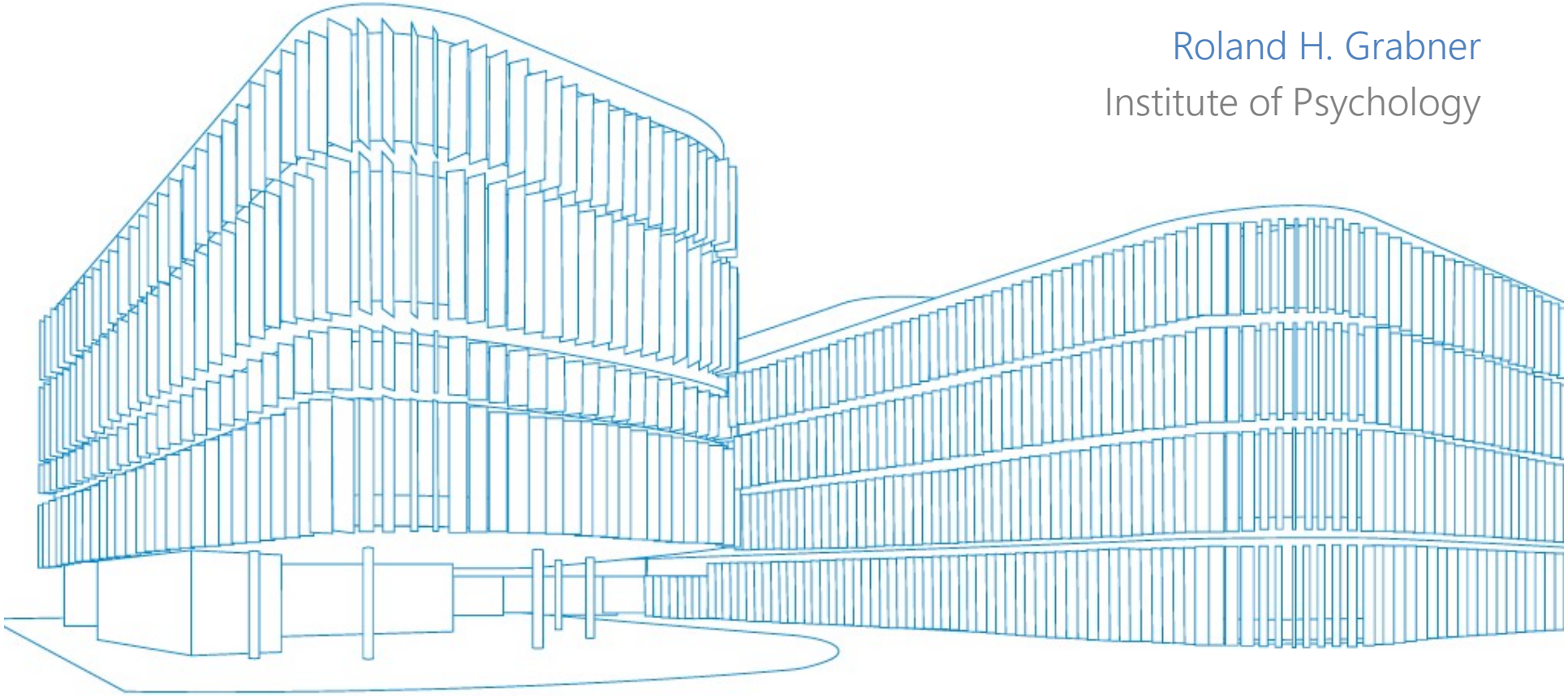
EDUCATIONAL NEUROSCIENCE

KARL-FRANZENS-UNIVERSITÄT GRAZ
UNIVERSITY OF GRAZ

Is there a mathematical brain?

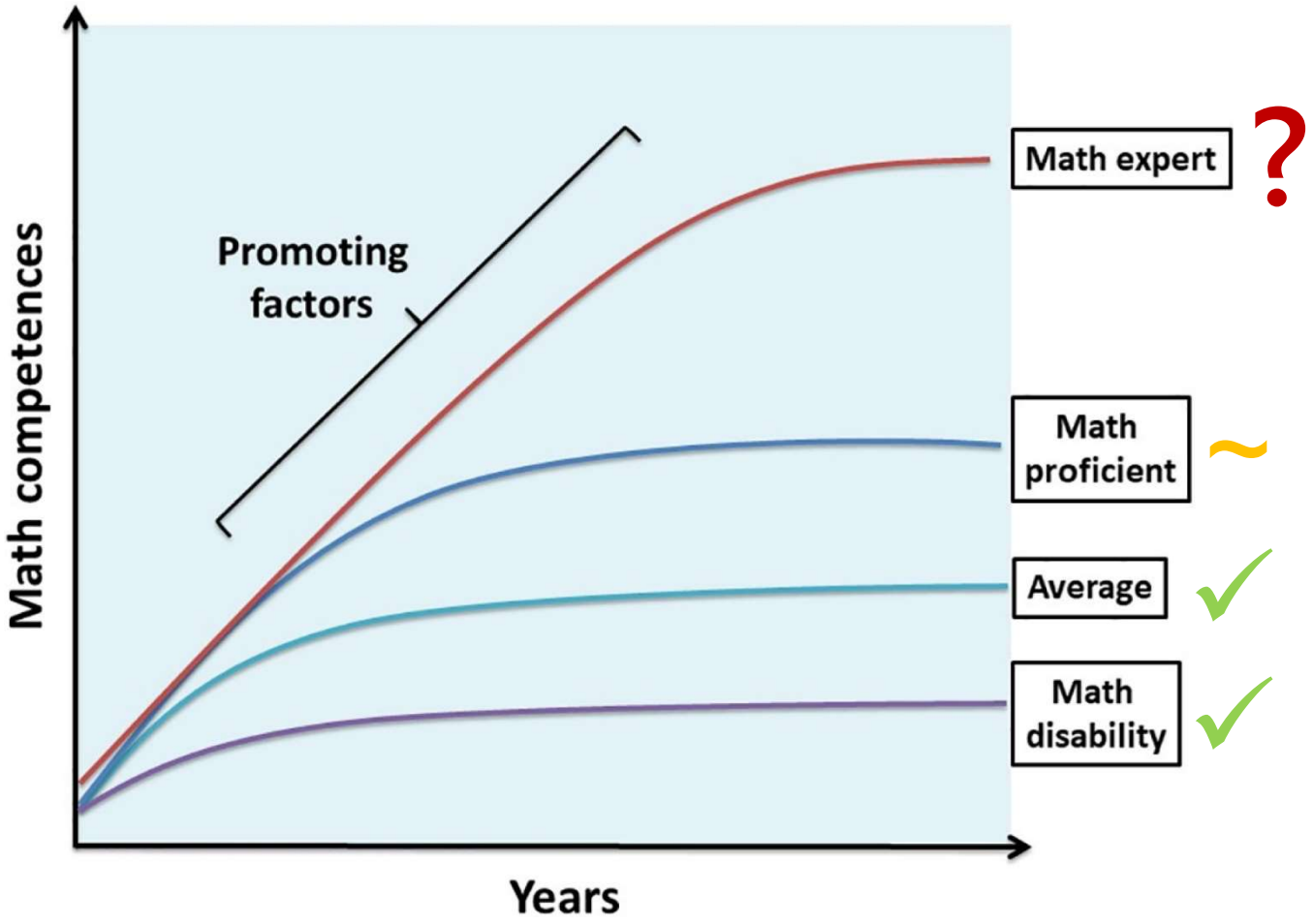
Psychological correlates of mathematical expertise

Roland H. Grabner
Institute of Psychology



Developmental trajectories

in mathematics



Sella & Cohen Kadosh (2018)

Promoting factors

of expertise development

Deliberate practice *What and how much?*

Domain-general abilities *Intelligence, working memory, …*

Domain-specific abilities *Cardinality, ordinality, arithmetic, …*

Domain-general personality *Big Five, Need for Cognition, …*

Domain-specific personality *Math-related attitudes, motivation, etc.*

Psychological correlates

of mathematical expertise

Michaela Meier
PhD student

- First systematic investigation of cognitive abilities and personality traits related to math expertise

- *N* = 105 adults
  - Mathematicians: Individuals who study or have studied math
  - Non-mathematicians: Subjects with no to minimal math content *(Teaching, Law, Translation, History, Philosophy, …)*

Matching for
1) gender, age, professional experience
2) general intelligence

Meier, Vogel, & Grabner (2021). *Journal of Expertise.*

Matched sample

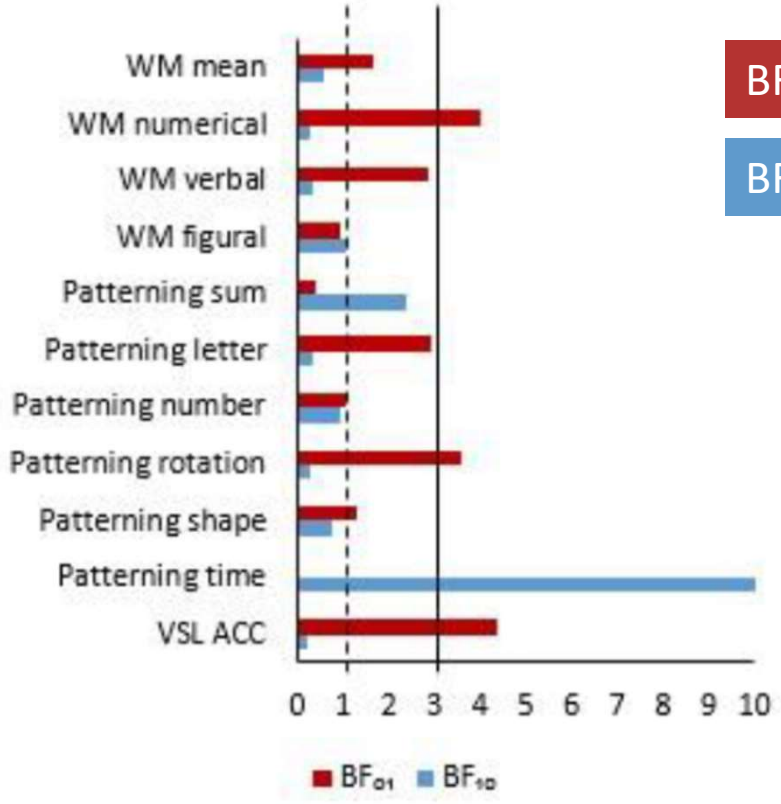
N = 84 (42 math, 42 non-math)

Table 1. Descriptive statistics and Bayesian statistics (Bayesian t-test) for mathematicians (Math.) and non-mathematicians (Non-math.)

Variable	Math. *M* (*SD*)	Non-math. *M* (*SD*)	*BF01* *No difference*	*BF10* *Difference*
Age (years)	29.31 (12.00)	29.07 (8.62)	4.37	0.23
Experience (years)	10.35 (11.92)	9.37 (8.68)	4.06	0.25
General intelligence (raw score)	176.57 (22.85)	171.79 (23.67)	2.98	0.34
Numerical intelligence (raw score)	58.29 (12.67)	51.74 (13.55)	0.55	1.81
Verbal intelligence (raw score)	42.81 (7.57)	46.36 (7.25)	0.46	2.16
Figural intelligence (raw score)	75.48 (10.53)	73.69 (12.42)	3.52	0.28
Mathematical achievement (raw score)	**28.41 (2.74)**	**18.79 (6.04)**	**0.00**	**408,800,000,000**
Hours spent with mathematics	**19,351 (21,325)**	**4,651 (12,139)**	**0.01**	**116.76**
Math grade (1 to 5)[b]	**1.19 (0.46)**	**2.33 (1.00)**	**0.00**	**3,928,000**
Grade average (1 to 5) [b]	2.13 (2.19)	1.75 (0.69)	2.64	0.38

Results

Domain-general cognitive abilities



1a. Math. vs. Non-math.

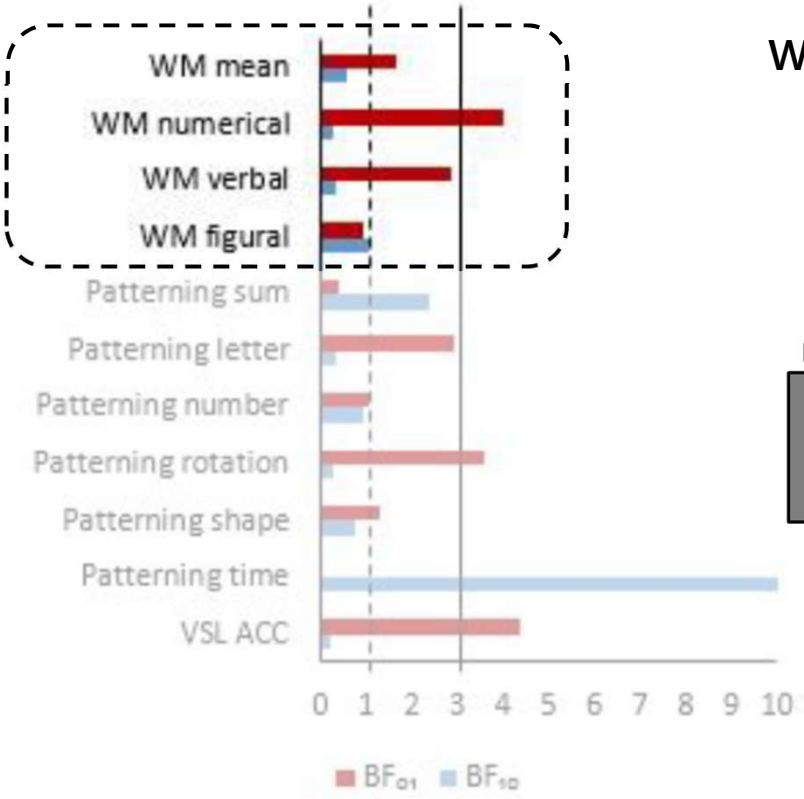
BF_{01}: similarity between math and non-math

BF_{10}: difference between math and non-math

1 < BF < 3:	anecdotal evidence
3 < BF < 10:	moderate evidence
BF > 10:	strong evidence

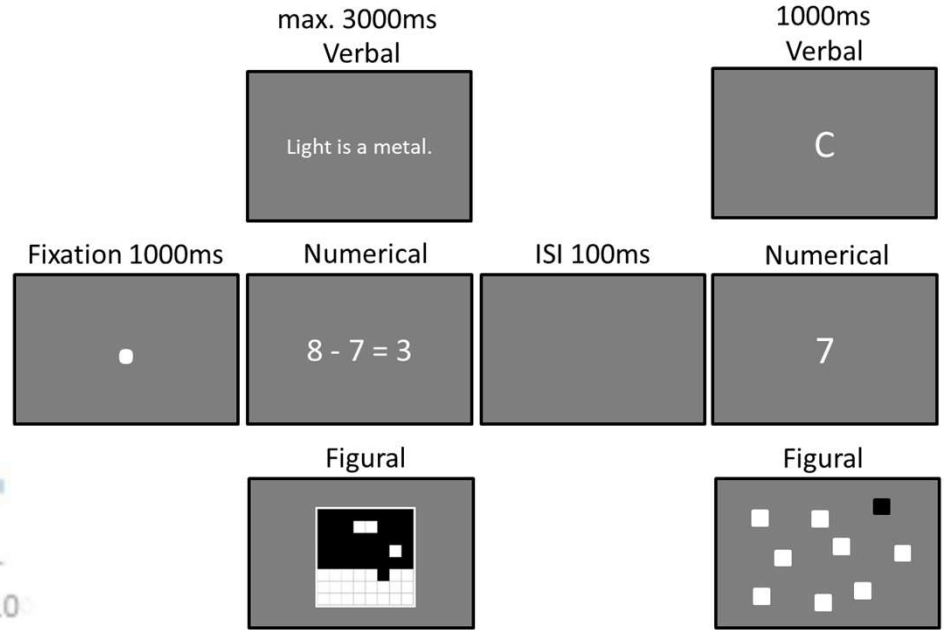
Results

Domain-general cognitive abilities



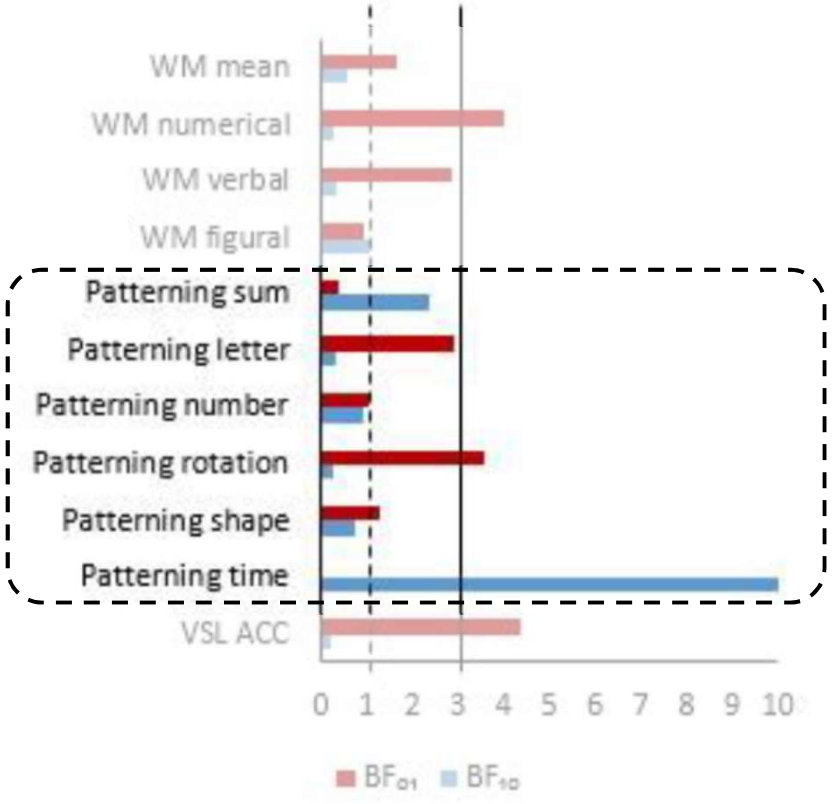
1a. Math. vs. Non-math.

Working memory (WM): Complex span task

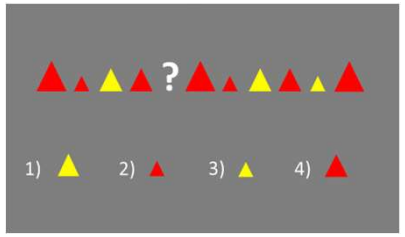


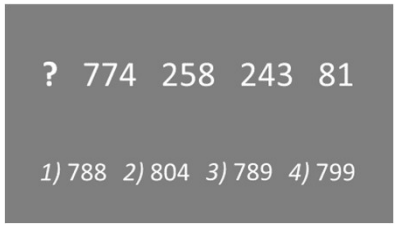
Results

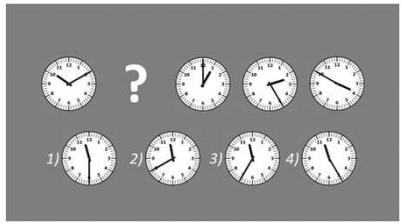
Domain-general cognitive abilities

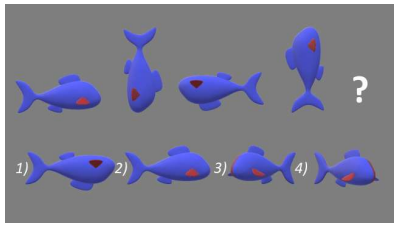


1a. Math. vs. Non-math.



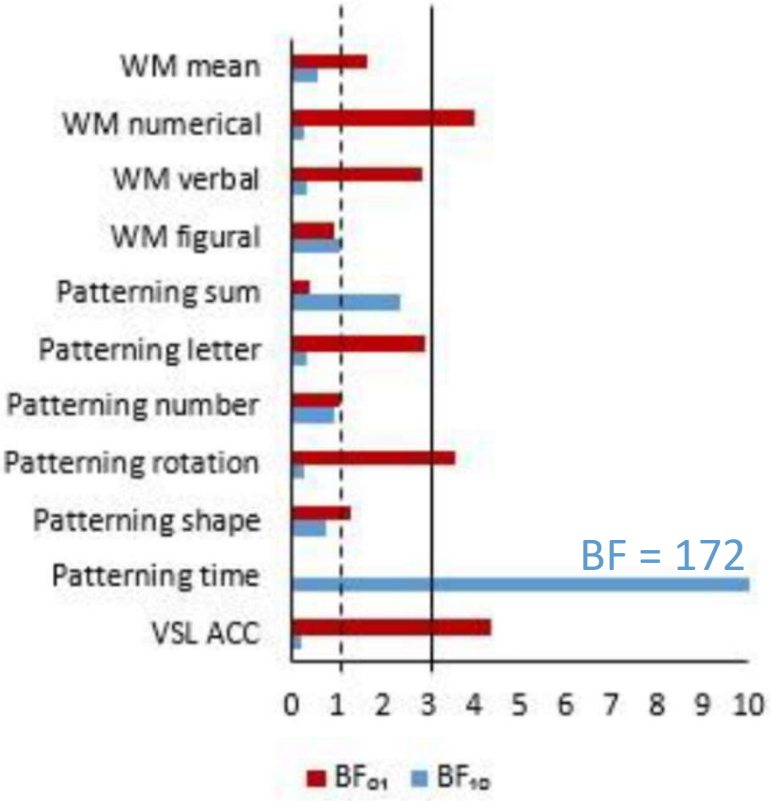




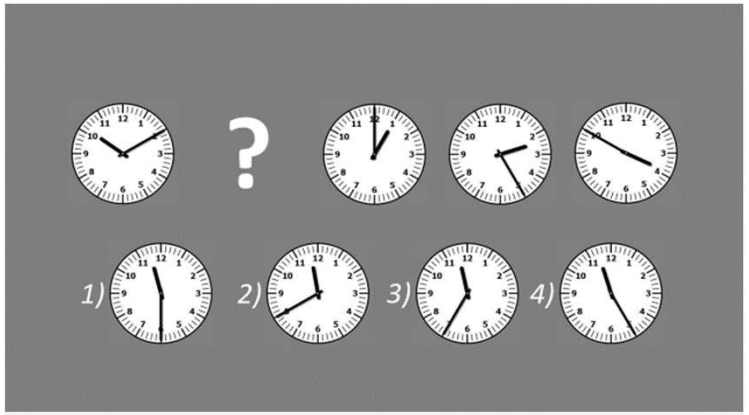


Results

Domain-general cognitive abilities

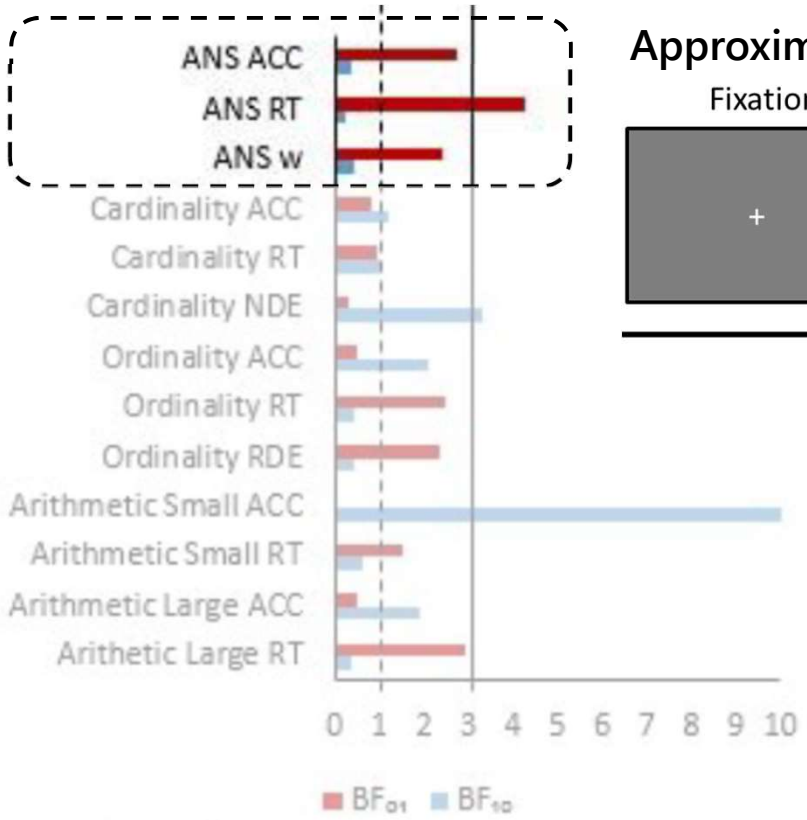


1a. Math. vs. Non-math.

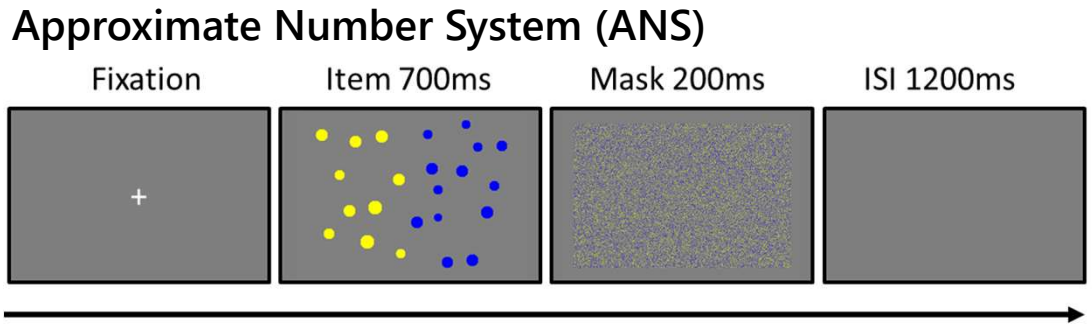


Results

Domain-specific cognitive abilities

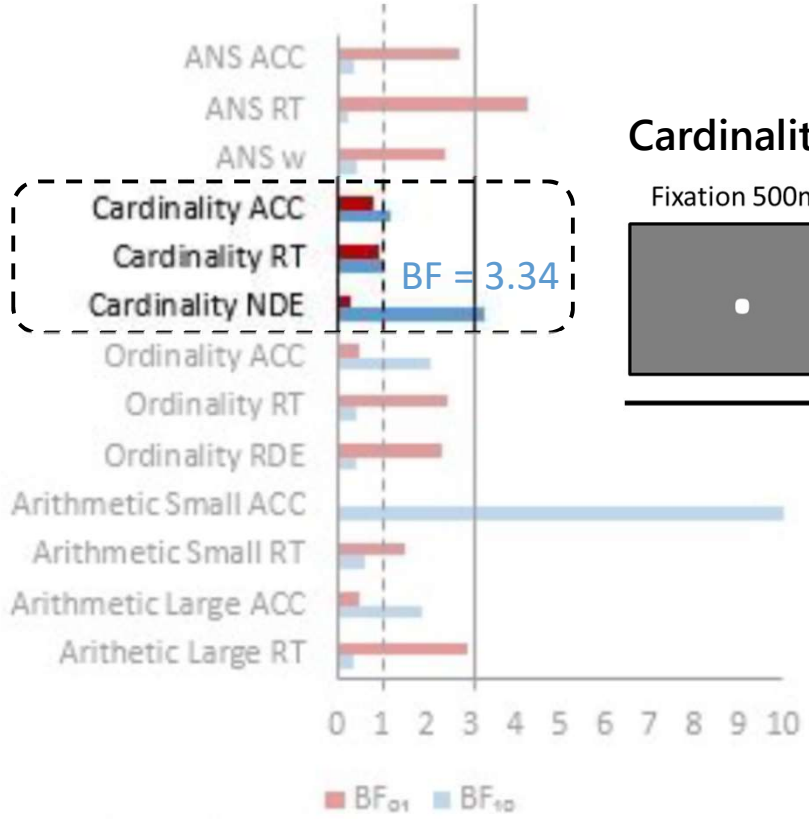


2a. Math. vs. Non-math.



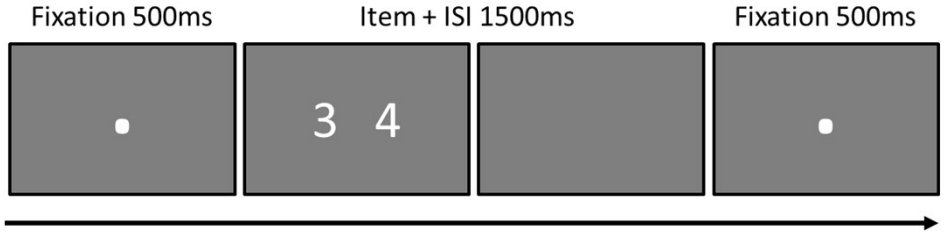
Results

Domain-specific cognitive abilities



2a. Math. vs. Non-math.

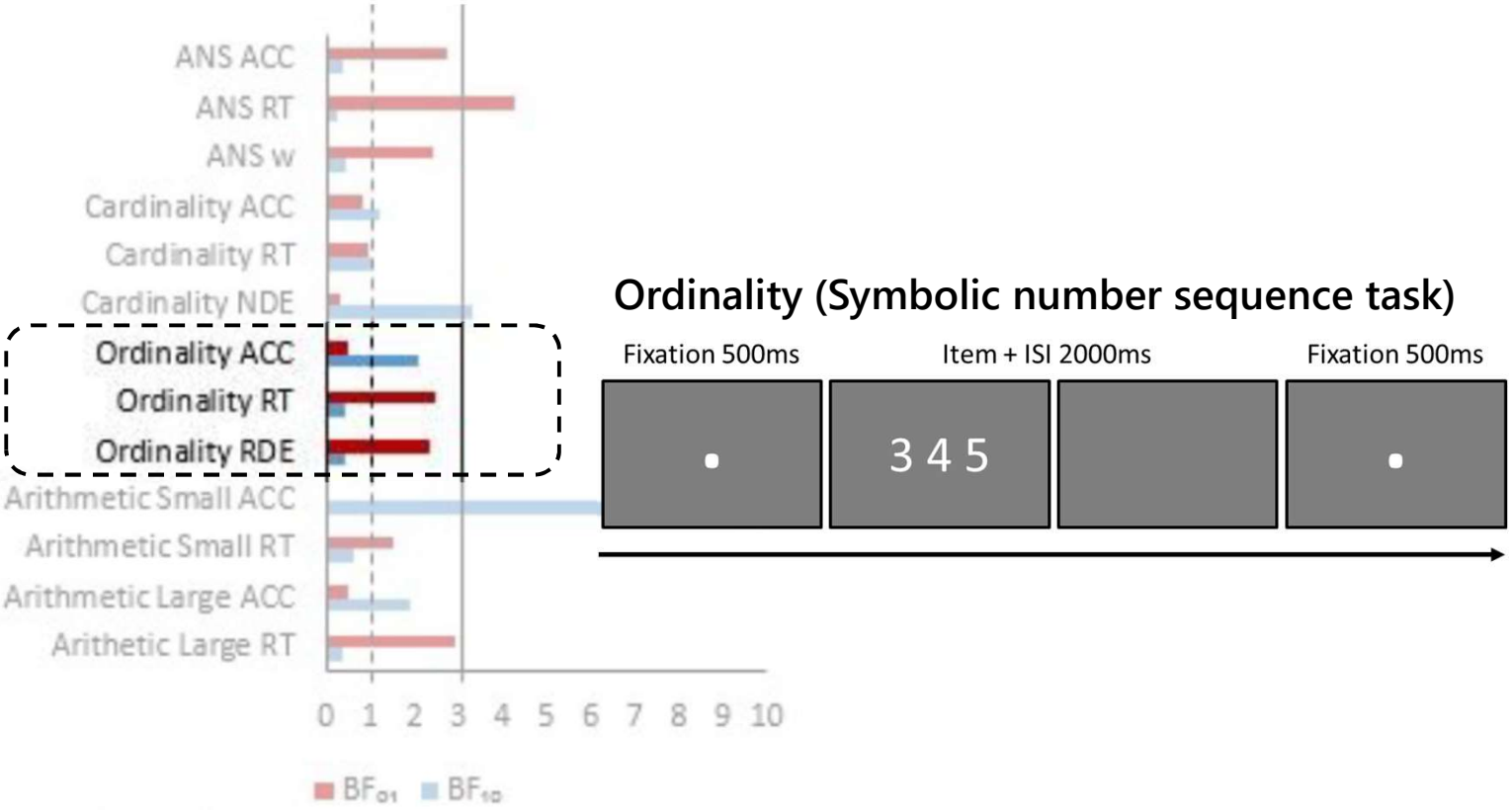
Cardinality (Symbolic number comparison task)



NDE	**0.11 (0.05)**	**0.14 (0.06)**
	Math	Non-math

Results

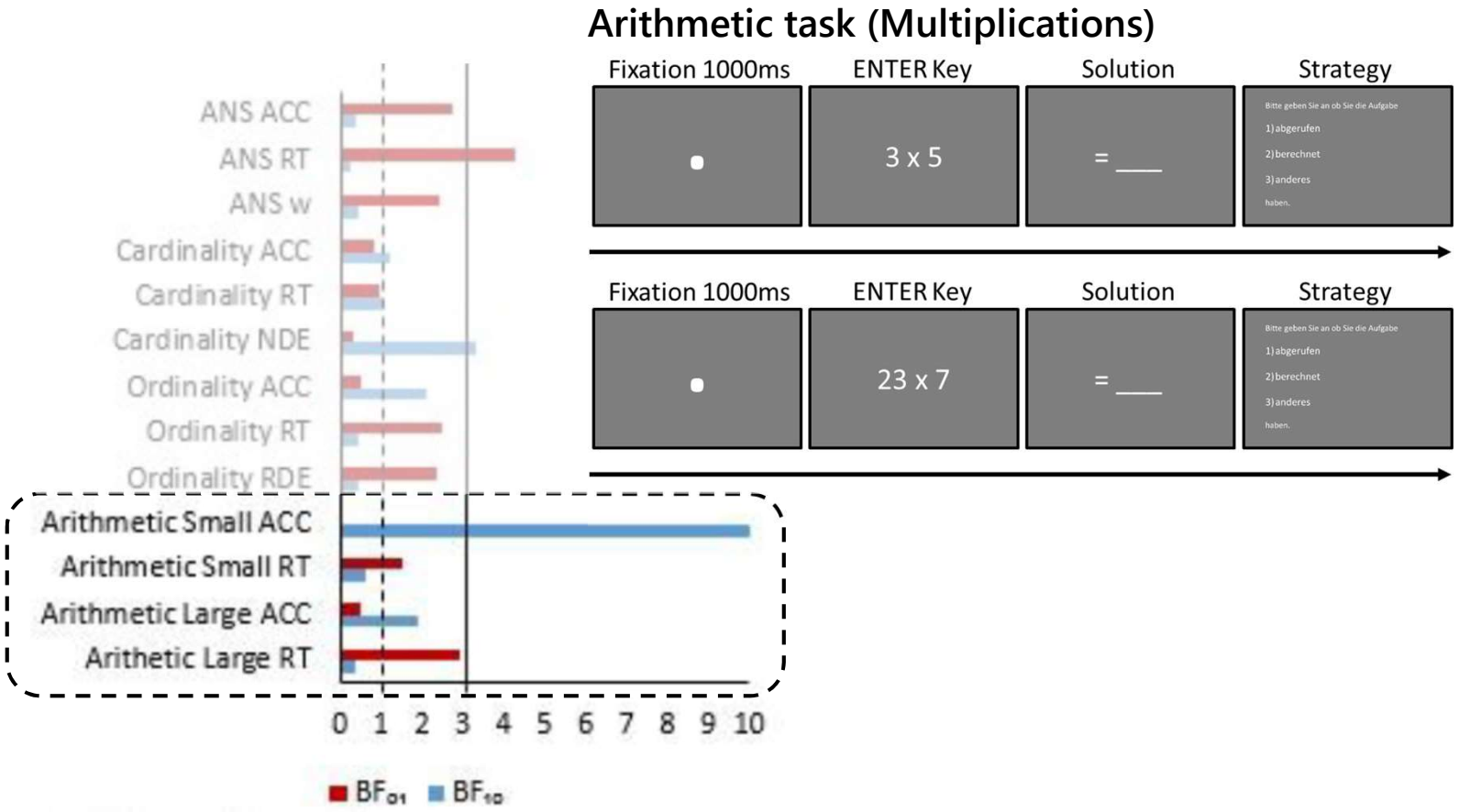
Domain-specific cognitive abilities



2a. Math. vs. Non-math.

Results

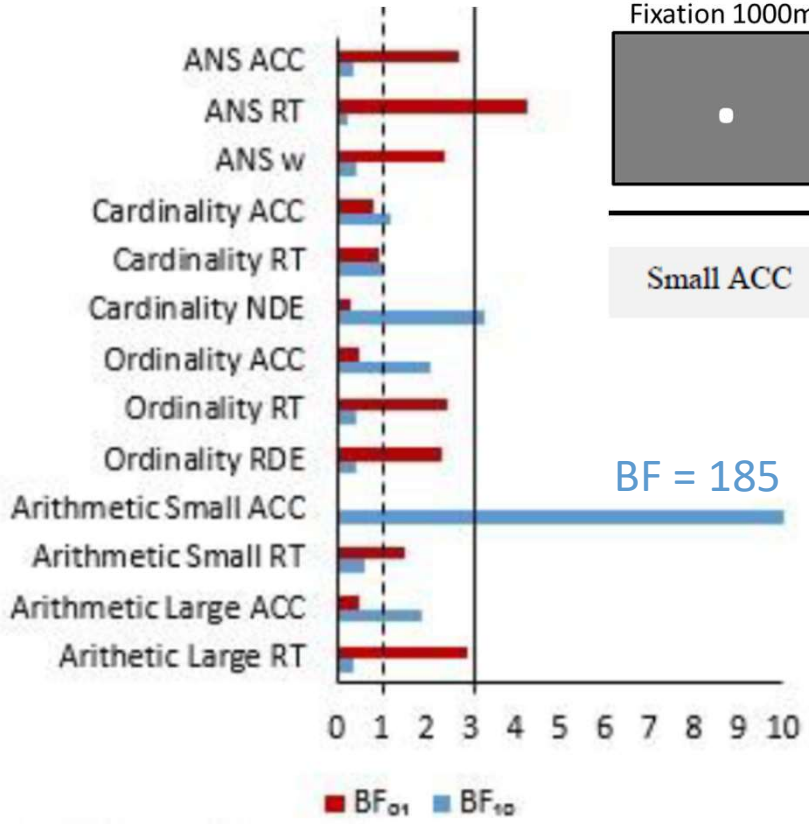
Domain-specific cognitive abilities



2a. Math. vs. Non-math.

Results

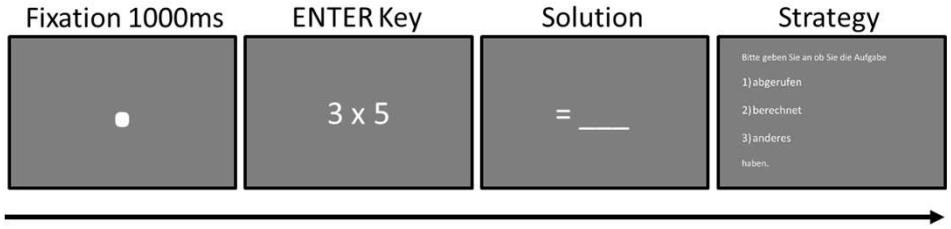
Domain-specific cognitive abilities



2a. Math. vs. Non-math.

BF = 185

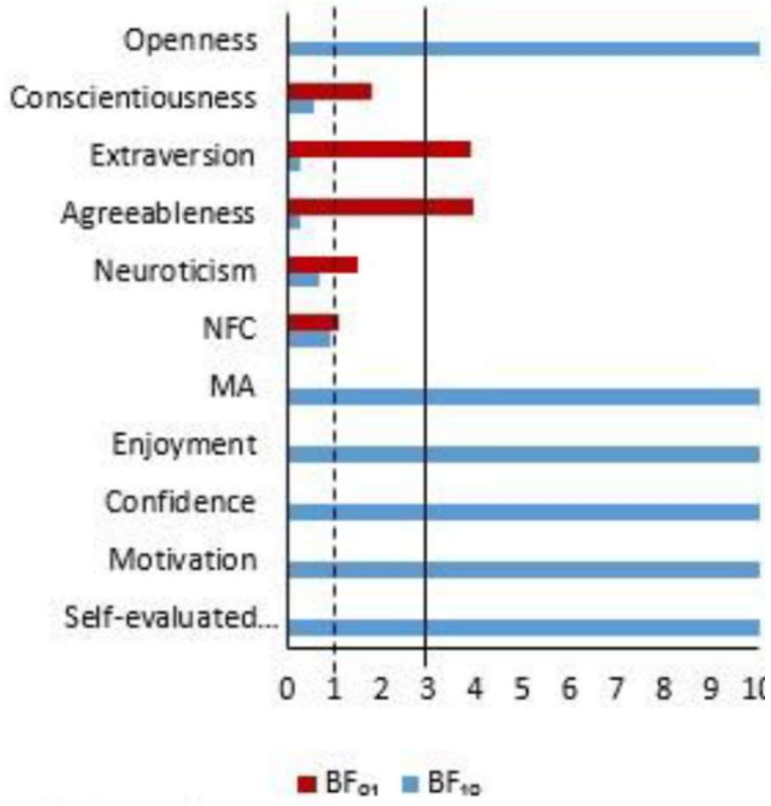
Arithmetic task (Multiplications)



	Math	Non-math
Small ACC	0.99 (0.02)	0.96 (0.04)

Results

Domain-general and domain-specific personality traits



3a. Math. LE vs. Math. HE

BF = 171

		Math	Non-math
Big Five (Likert 1-5)	Openness	**3.53 (0.71)**	**4.11 (0.61)**
	Conscientiousness	3.85 (0.59)	4.03 (0.56)
	Extraversion	3.29 (0.62)	3.36 (0.63)
	Agreeableness	3.80 (0.72)	3.87 (0.66)
	Neuroticism	2.27 (0.63)	2.50 (0.76)
Math Anxiety (Likert 1-5)		**1.51 (0.41)**	**2.33 (0.77)**
Enjoyment of mathematics (Likert 1-5)		**4.55 (0.55)**	**2.98 (1.18)**
Confidence in mathematics (Likert 1-5)		**3.88 (0.74)**	**2.71 (0.94)**
Motivation in mathematics (Likert 1-5)		**4.43 (0.59)**	**2.81 (1.13)**
Self-evaluated math competencies (Likert 1-6)		**4.69 (0.54)**	**4.12 (0.64)**

Summary: Promoting factors

of expertise development

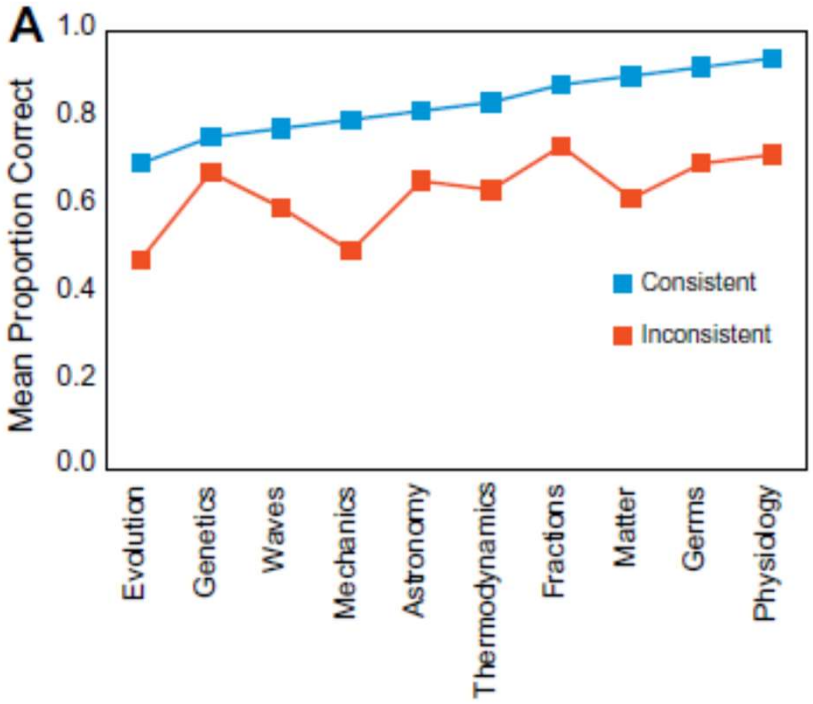
Deliberate practice	First gross estimate
Domain-general abilities	**Patterning time**: duodecimal, sexagesimal systems
Domain-specific abilities	**Numerical distance effect**: more accurate representations **Simple arithmetic**: better arithmetic fact network
Domain-general personality	**Openness**
Domain-specific personality	**Math anxiety:** less **Attitudes:** more enjoyment, confidence, motivation **Self-evaluation**: higher

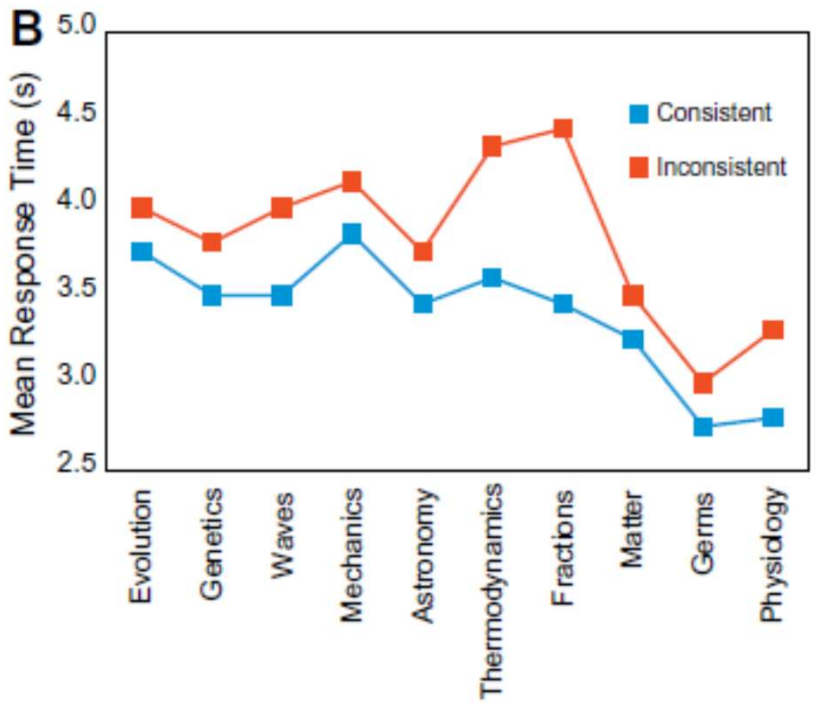
Conceptual knowledge

The „Shtulman“ interference effect

Consistent: naïve = scientific theories
Inconsistent: naïve ≠ scientific theories

Δ: interference effect





Shtulman & Valcarcel (2012). *Cognition.*

Conceptual knowledge

and math proficiency

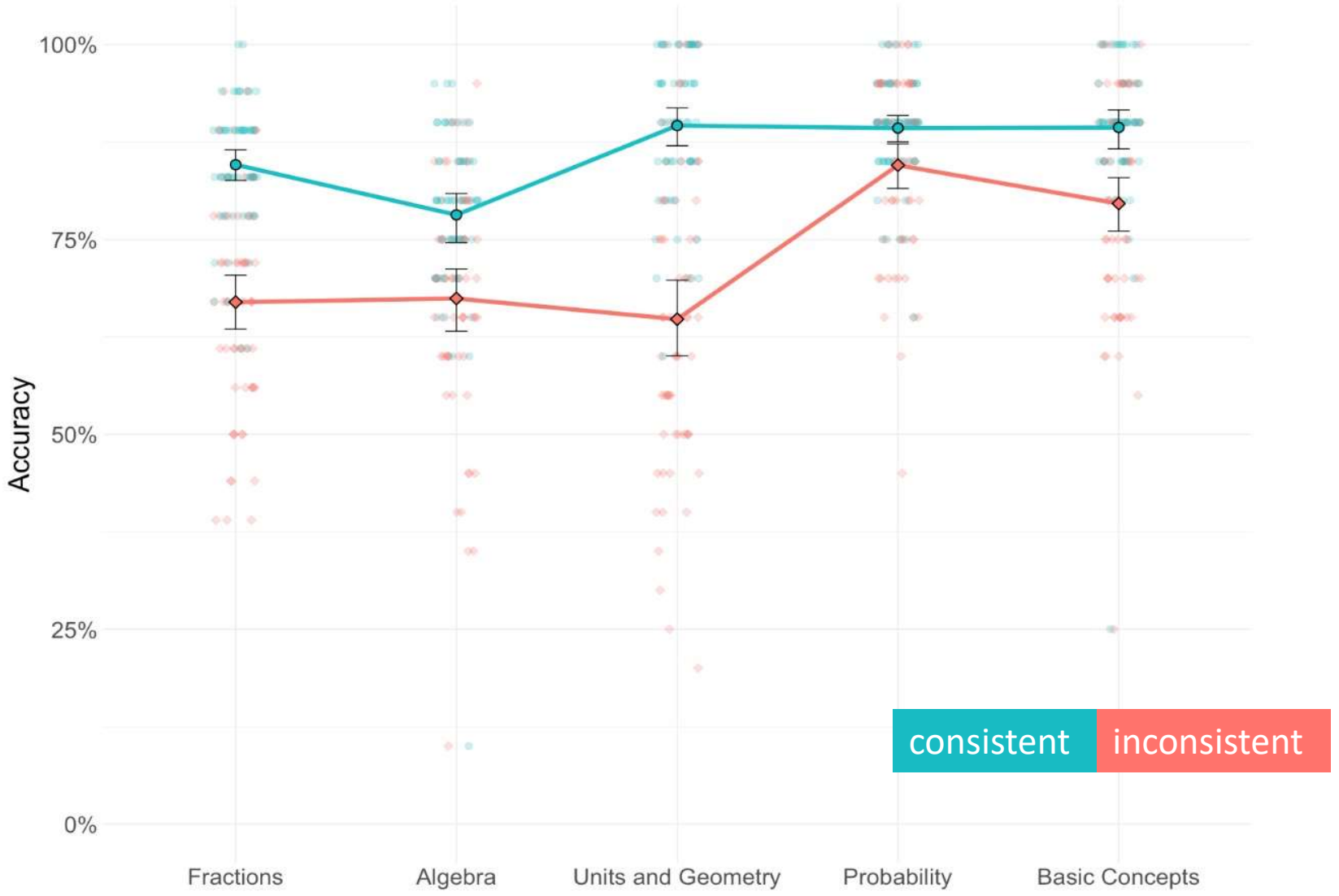
Research questions:

- Does the „Shtulman“ interference effect generalize to the formal domain of mathematics?
- Is the interference effect related to mathematical achievement and inhibitory control?

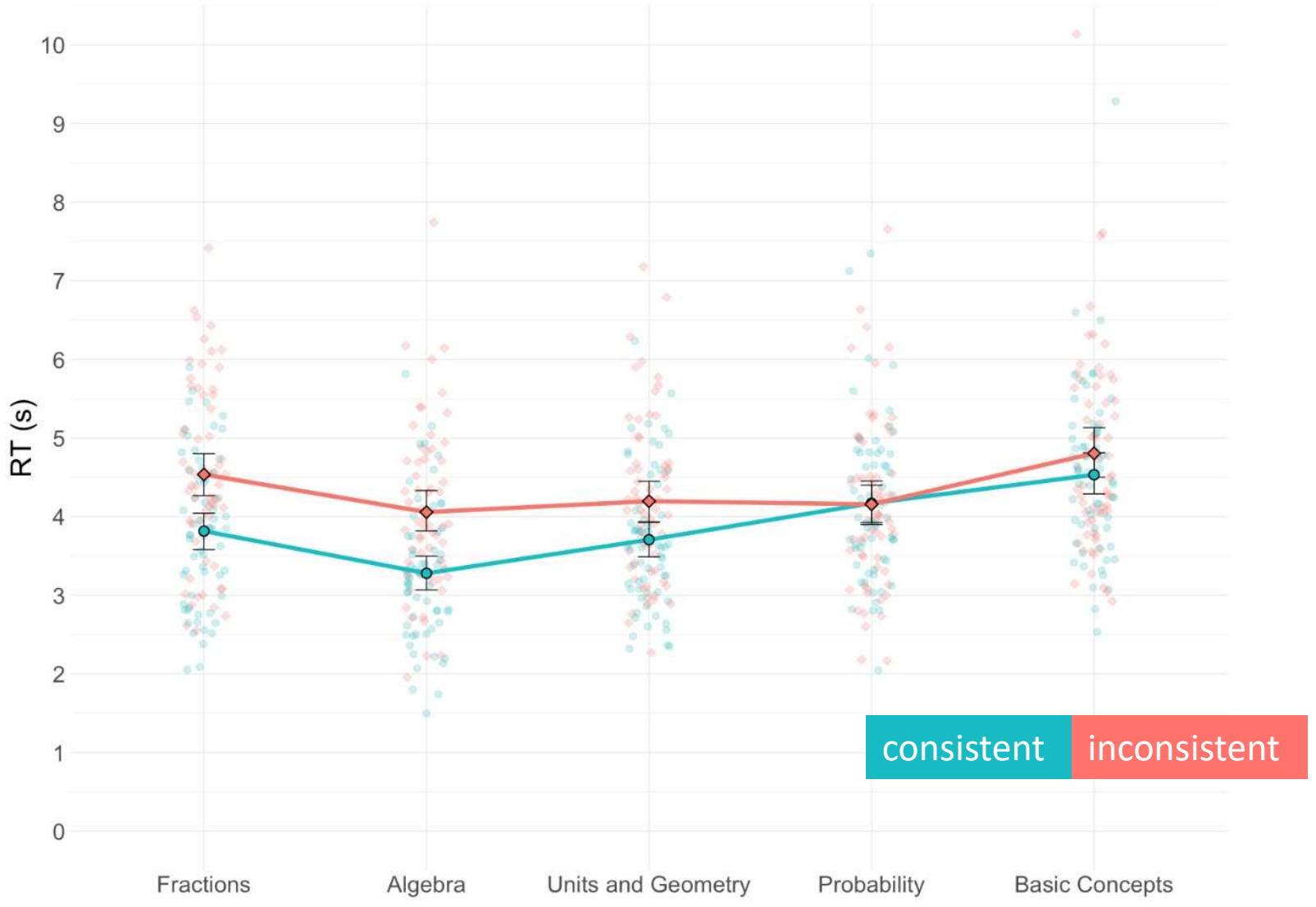
Method:

- *N* = 39 adult students
- 200 statements from 5 math domains
  (fractions, algebra, units and geometry, probability, basic concepts)
- Further measures:
  - Math competence test
  - Arithmetic fluency
  - Math grade
  - Picture-word task (inhibitory control)

Results: Accuracy



Results: Reaction times



Results: Correlations

Table 1

Standardized Regression Coefficients for Mathematical Achievement and Inhibitory Control as Predictors of Interference Strength

	Mathematical achievement			Inhibitory control	
Interference in mathematics	Mathematical competence	Arithmetic fluency	Math grade	Accuracy	RT
Accuracy	-.68***	-.31*	.37**	-.24	-.05
RT	-.14	-.14	.15	.05	.04

Note. RT = reaction time. $N = 62$ for all variables except math grade ($N = 58$). A lower math grade indicates higher mathematical achievement. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Conceptual knowledge

and math expertise

Michaela Meier
PhD student

Dennis Wambacher
Master student

Research questions:

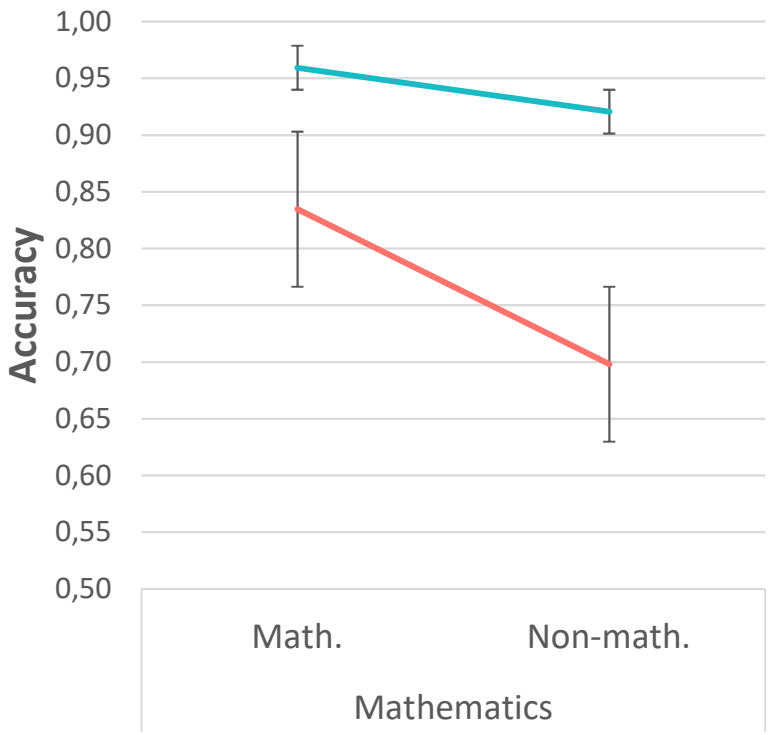
- Do mathematicians and non-mathematicians differ in the „Shtulman“ interference effect?

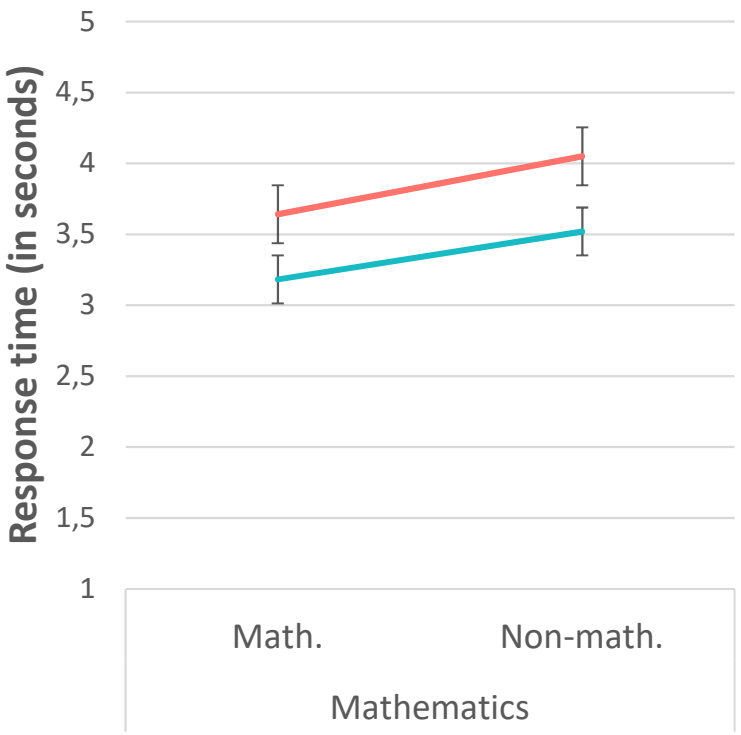
Method:

- *N* = 61 adults (30 mathematicians, 31 non-mathematicians)
- 100 statements from 4 math domains
  (fractions, algebra, units and geometry, basic concepts)

Variable	Math. *M* (*SD*)	Non-math. *M* (*SD*)		
Age (years)	23.80 (3.93)	24.61 (4.35)	p = .471	d = -0.19
Experience (years)	4.11 (4.00)	4.28 (3.48)	p = .895	d = -0.04
General intelligence (raw score)	191.52 (28.18)	183.97 (25.72)	p = .348	d = 0.28
Numerical Intelligence (raw score)	61.96 (12.74)	59.48 (13.26)	p = .526	d = 0.19
Verbal intelligence (raw score)	45.20 (7.23)	48.00 (8.90)	p = .213	d = -0.34
Figural Intelligence (raw score)	84.12 (15.87)	76.81 (12.97)	p = .063	d = 0.53
Math achievement (raw score)	**28.36 (3.28)**	**20.90 (5.21)**	**p < .001**	**d = 1.70**

Preliminary results





consistent | inconsistent

Summary: Conceptual knowledge

Interference effect

- „Shtulman“ interference effect (in accuracy)
  - is negatively related to mathematical competence (also beyond inhibitory control)
  - is smaller in mathematicians
- Mathematicians may be better able to inhibit naïve theories in mathematics

Is there a mathematical brain?

Next steps in our research

- Development of
  - expert memory tasks
  - mathematical creativity tasks
- Further comparisons of math and non-math
  - Brain activity during mathematical Shtulman paradigm
  - Brain structure

EDUCATIONAL NEUROSCIENCE

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WKO

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Thank you!

https://psychologie.uni-graz.at/en/educational-neuroscience/researching/