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VIEW of SCIENCE

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Measures of Cognitive Control Fail to Form a Coherent Factor – And Methodological Limitations Cannot Explain That Away

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Individual-differences research in cognitive control

- For more than 20 years, previous research has put forward **cognitive control as a cognitive psychometric construct**

  (e.g., Engle et al., 1999, *J Exp Psychol Gen*; Kane et al., 2004, *J Exp Psychol Gen*; Miyake et al., 2000, *Cognitive Psychol*).

- However, recent research has **failed to provide strong evidence for a psychometric construct of cognitive control**

  (e.g., Karr et al., 2018, *Psychol Bull*; Rey-Mermet et al., 2018, *J Exp Psychol Learn Mem Cogn,* Rey-Mermet et al., 2019, *J Exp Psychol Gen,* Rey-Mermet et al., 2020, *PlosOne*; von Bastian et al., 2020, *PsyArXiv*).

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Four methodological limitations

1. the **low** **reliability** of **the** **cognitive-control** **measures**
2. the use of **difference measures** to assess **cognitive control**
3. the **neglect of individual differences in** **speed-accuracy trade-offs** when only speed or accuracy is used as dependent variable
4. the difficulty of **isolating** **cognitive control** **from** **measurement error**

Main question

- Can **a psychometric construct of** **cognitive control** be established **when** **these methodological limitations** **are overcome**?

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Dataset from Rey-Mermet et al. (2018, *J Exp Psychol Learn Mem Cogn*)

color Stroop	arrow Flanker
Simon	letter Flanker
global-local task	number Stroop
negative compatibility	positive compatibility
Antisaccade	n-2 repetition cost
stop-signal	

Note. Sample = 107 young adults

Reliability

Task	Estimate
Antisaccade (accuracy)	.95
Stop signal (SSRT)	.88
Color Stroop	.63
Simon	.68
Negative compatibility	.54
Local task	.54
Arrow flanker	.64
Letter flanker	.37
Number Stroop	.66
Positive compatibility	.61
N-2 repetition cost	.27

Note. Spearman-Brown corrected split-half reliability computed using a permutation-based split-half approach with 5000 random splits (except for the stop-signal task; Parsons et al., 2019, *AMPPS*).

Correlations

	1.	2.	3.	4.	5.	6.
1. antisaccade	-					
2. stop signal	**-.22**	-				
3. color Stroop	**.19**	-.05	-			
4. Simon	-.05	-.14	-.02	-		
5. arrow flanker	-.17	-.02	**-.21**	.04	-	
6. number Stroop	-.02	-.03	.01	.00	**.26**	-
7. positive compatibility	.01	-.04	-.08	.14	.05	.12

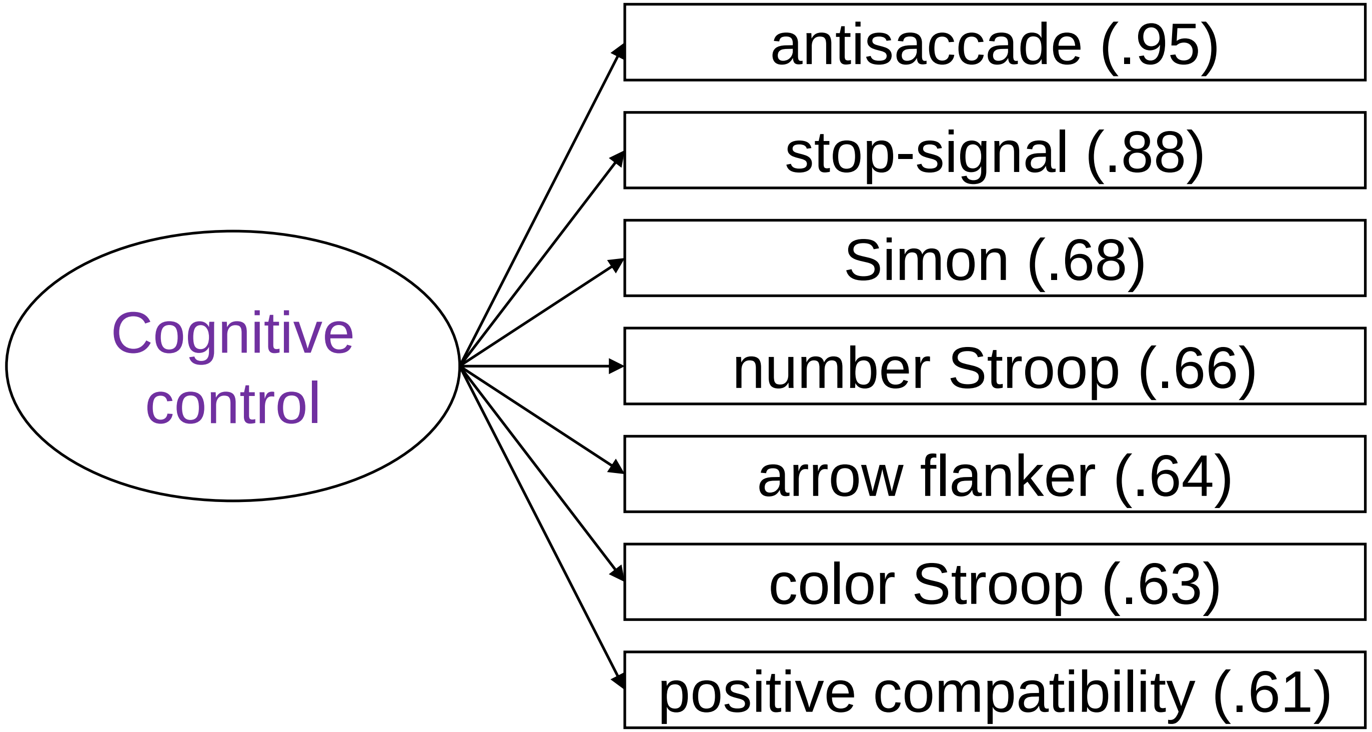
bold = *p* < .05

Correlations

	1.	2.	3.	4.	5.	6.
1. antisaccade	-					
2. stop signal	**-.22**	-				
3. color Stroop	**.19**	-.05	-			
4. Simon	-.05	-.14	-.02	-		
5. arrow flanker	-.17	-.02	**-.21**	.04	-	
6. number Stroop	-.02	-.03	.01	.00	**.26**	-
7. positive compatibility	.01	-.04	-.08	.14	.05	.12

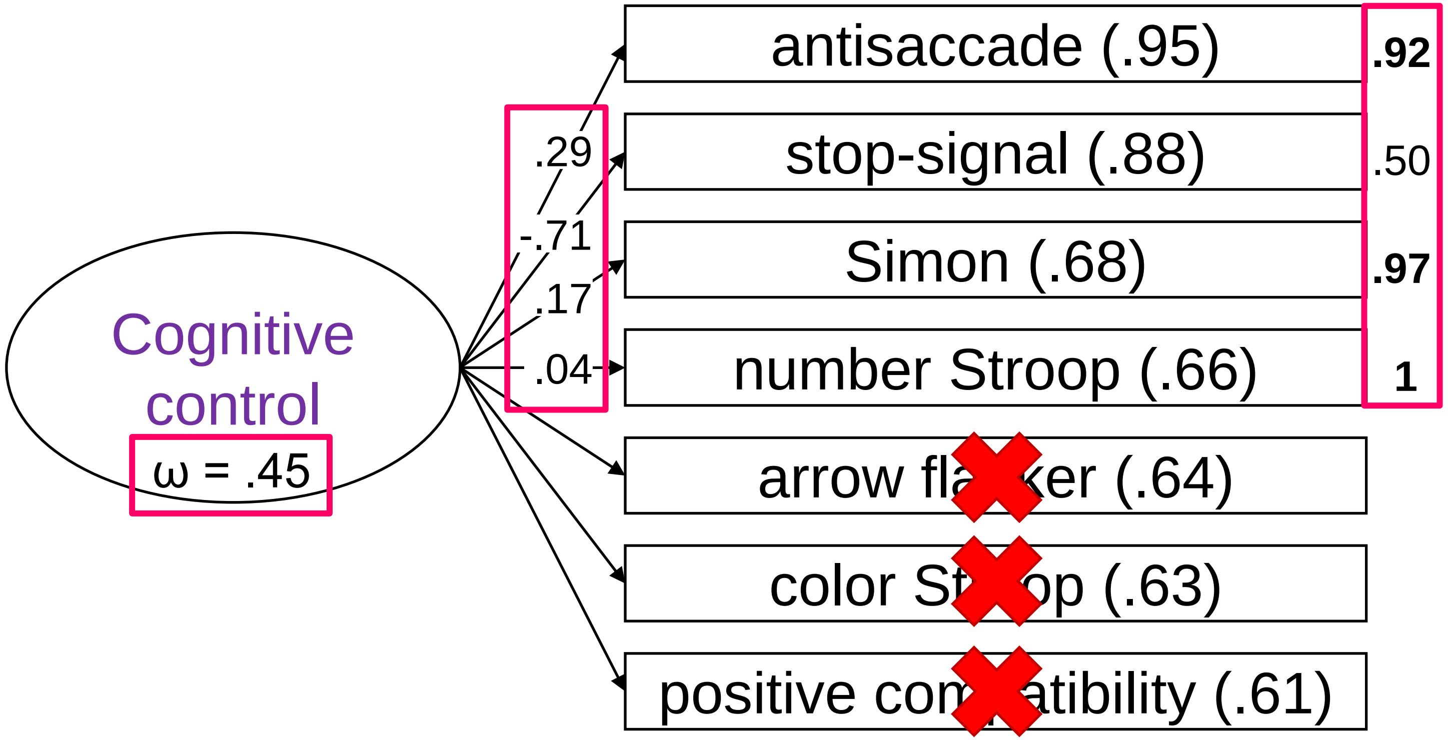
bold = *p* < .05
$BF_{10} > 3$
$BF_{01} > 3$

Structural equation modeling



Note. Reliability estimates are presented in parentheses.

Structural equation modeling



Note. Reliability estimates are presented in parentheses. Bold = $p < .05$

CFI = 1, SRMR = .03

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Reliability

Task	Trial type	Estimate
Antisaccade (accuracy)	-	.95
Stop signal	SSRT	.88
Color Stroop	Incongruent	.97
	Congruent	.98
Simon	Incongruent	.97
	Congruent	.98
Arrow flanker	Incongruent	.98
	Congruent	.98
Number Stroop	Incongruent	.97
	Congruent	.98
Positive compatibility	Incongruent	.94
	Congruent	.95

Note. Spearman-Brown corrected split-half reliability computed using a permutation-based split-half approach with 5000 random splits (except for the stop-signal task; Parsons et al., 2019, *AMPPS*).

Correlations

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. antisaccade	-										
2. stop signal	**-.22**	-									
3. color Stroop: incongruent	.07	.16	-								
4. color Stroop: congruent	.01	**.21**	**.94**	-							
5. Simon: incongruent	.07	.13	**.59**	**.59**	-						
6. Simon: congruent	.08	.16	**.57**	**.58**	**.93**	-					
7. arrow flanker: incongruent	-.07	.12	**.63**	**.67**	**.59**	**.57**	-				
8. arrow flanker: congruent	-.01	.15	**.67**	**.69**	**.63**	**.62**	**.95**	-			
9. number Stroop: incongruent	-.07	**.21**	**.61**	**.64**	**.57**	**.53**	**.61**	**.60**	-		
10. number Stroop: congruent	-.07	**.26**	**.66**	**.68**	**.59**	**.55**	**.57**	**.57**	**.93**	-	
11. positive compatibility: incongruent	.05	.07	**.42**	**.41**	**.39**	**.38**	**.54**	**.57**	**.42**	**.44**	-
12. positive compatibility: congruent	.04	.08	**.38**	**.36**	**.36**	**.36**	**.46**	**.49**	**.35**	**.39**	**.87**

bold = *p* < .05

$BF_{10} > 3$

$BF_{01} > 3$

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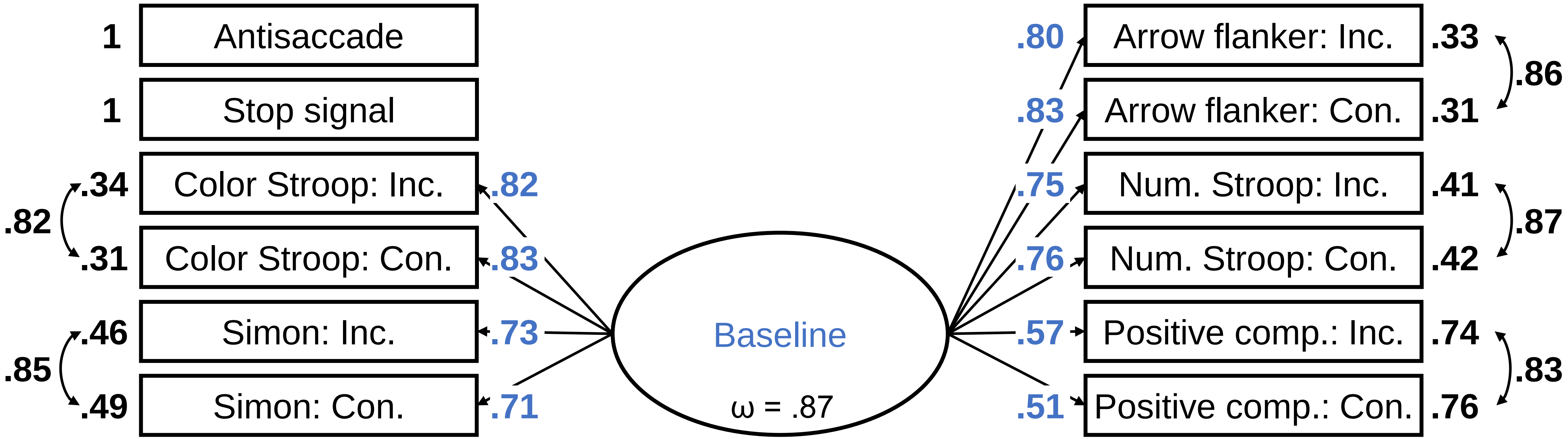
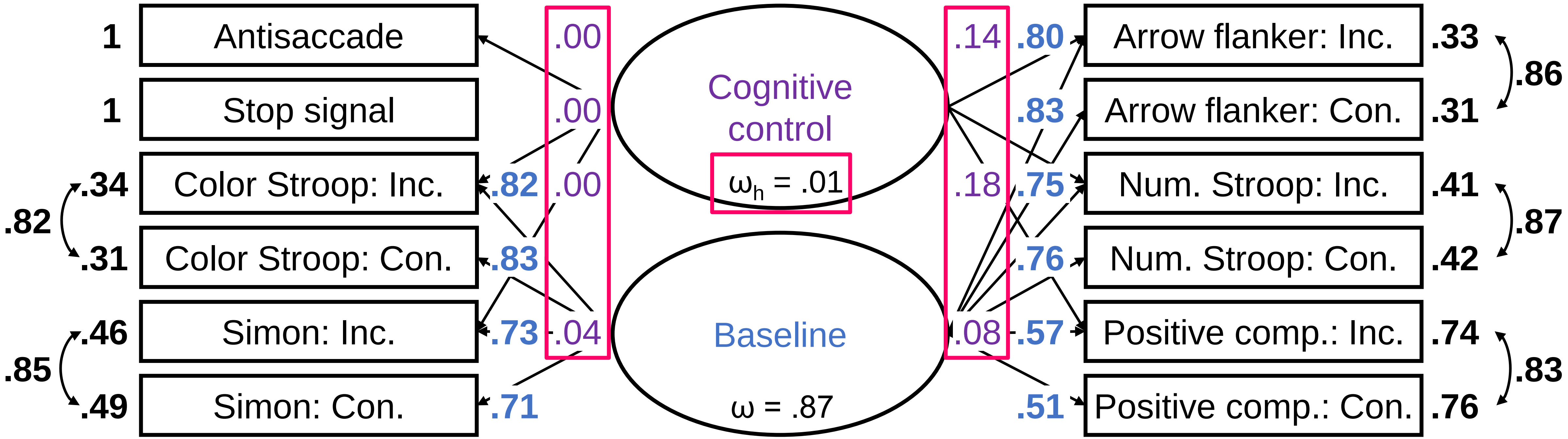
Structural equation modeling: Bifactor model



Note. Factor loadings were constrained to be positive. Bold = $p < .05$

CFI = .99, SRMR = .07

Structural equation modeling: Bifactor model



Note. Factor loadings were constrained to be positive. Bold = $p < .05$

CFI = .99, SRMR = .07

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- the **low reliability** of **the cognitive-control measures**
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stop-signal	

Note. Sample = 107 young adults

A hierarchical-Bayesian Wiener diffusion modeling was combined with structural equation modeling (SEM).

Differences in speed-accuracy trade-offs are considered because…

- The **diffusion model** is fitted to the **joint distribution of RT and accuracy**.
- The **diffusion model** separates **the person's speed-accuracy setting** (i.e., the boundary separation parameter) from **the quality of information processing** (i.e., the **drift rate**).

We expected to establish a coherent factor of **cognitive control** on the **drift-rate parameter**.

Measurement error is reduced because…

- The **Wiener diffusion model** predicts the **presence of long RTs**, thus accounting for **the right-skewed nature of the RT distribution**.
- We modeled the **variance-covariance matrix of the individual-level effects** as a parameter of the **hierarchical model**.
  $\Rightarrow$ Joint estimation (≠ two-step procedure used in previous research)
- …

Posterior Mean Correlations
Difference coding

bold = the 95% CI excludes 0

	1.	2.	3.	4.	5.	6.	7.
1. Color Stroop	-						
2. Number Stroop	-.02	-					
3. Arrow flanker	-.14	.03	-				
4. Letter flanker	-.09	.10	.26	-			
5. Simon	-.13	.04	.08	.21	-		
6. Local	.11	.03	.06	.09	.19	-	
7. Positive comp.	-.02	.03	.00	.16	.11	.07	-
8. Negative comp.	-.04	.16	.06	.12	.02	.04	.09

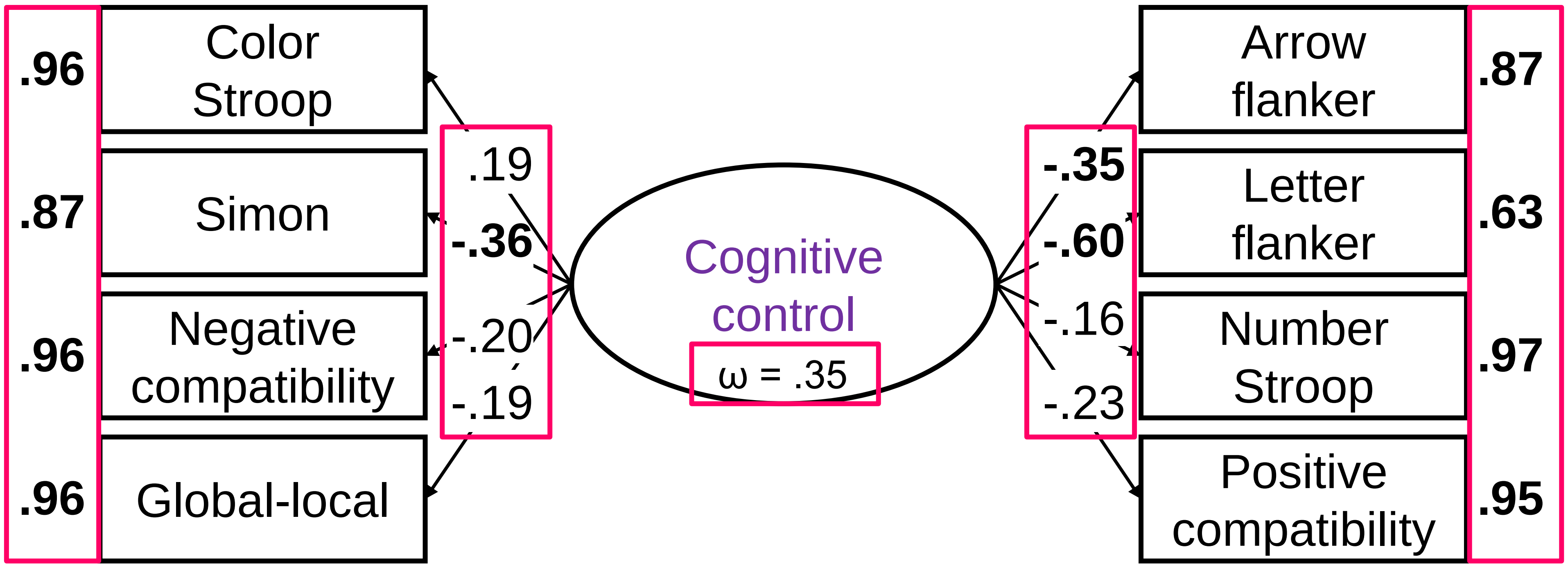
Posterior Mean Correlations + 95% Credibility Intervals
Difference coding

	1.	2.	3.	4.	5.	6.	7.
1. Color Stroop	-						
2. Number Stroop	-.02 [-.30, .26]	-					
3. Arrow flanker	-.14 [-.42, .17]	.03 [-.23, .30]					
4. Letter flanker	-.09 [-.37, .21]	.10 [-.18, .37]	.26 [-.01, .51]	-			
5. Simon	-.13 [-.40, .17]	.04 [-.18, .27]	.08 [-.15, .31]	.21 [-.04, .45]	-		
6. Local	.11 [-.21, .39]	.03 [-.25, .32]	.06 [-.22, .34]	.09 [-.21, .36]	.19 [-.08, .44]	-	
7. Positive comp.	-.02 [-.31, .27]	.03 [-.22, .28]	.00 [-.25, .25]	.16 [-.11, .41]	.11 [-.11, .33]	.07 [-.21, .35]	-
8. Negative comp.	-.04 [-.32, .23]	.16 [-.10, .41]	.06 [-.20, .33]	.12 [-.16, .37]	.02 [-.21, .25]	.04 [-.23, .30]	.09 [-.15, .35]

- The intervals are quite narrow around 0
- They exclude medium or large correlations.

⇒ **The correlations are estimated quite precisely!**

Structural equation modeling: Difference coding



Note. Bold = $p < .05$

CFI = 1, SRMR = .05

(see Rey-Mermet et al., 2021, *PsyArXiv*)

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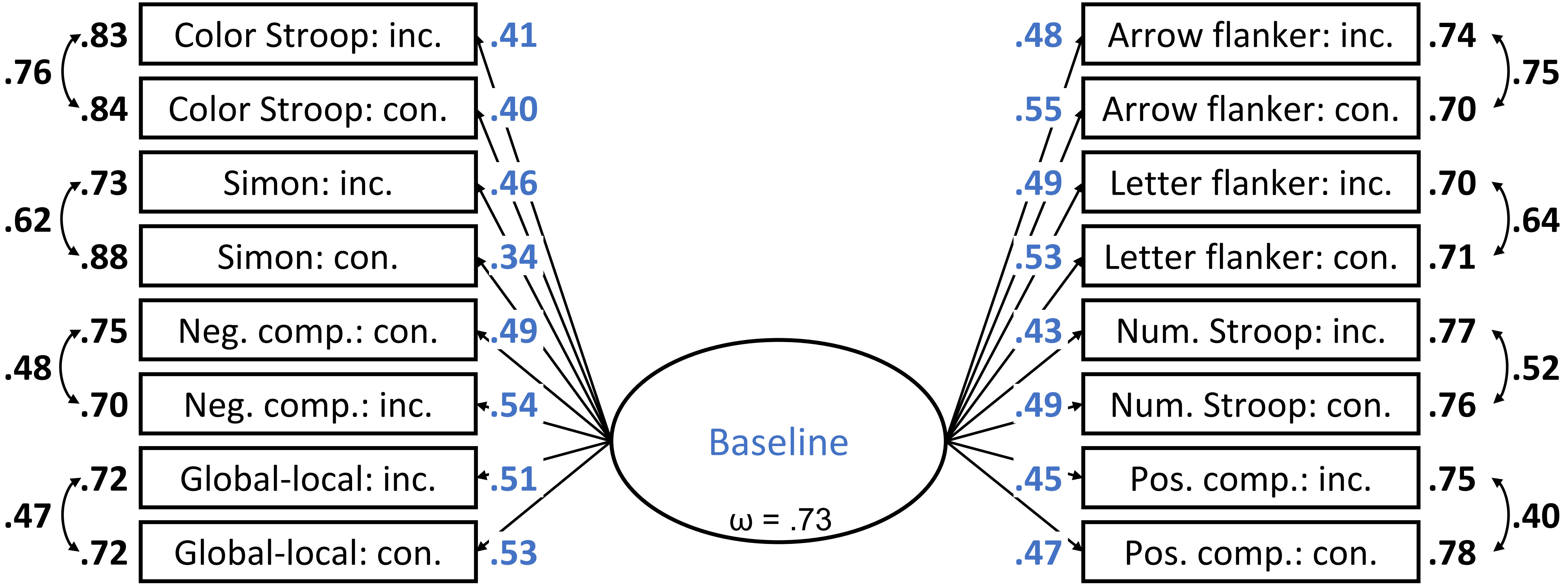
Structural equation modeling: Bifactor model

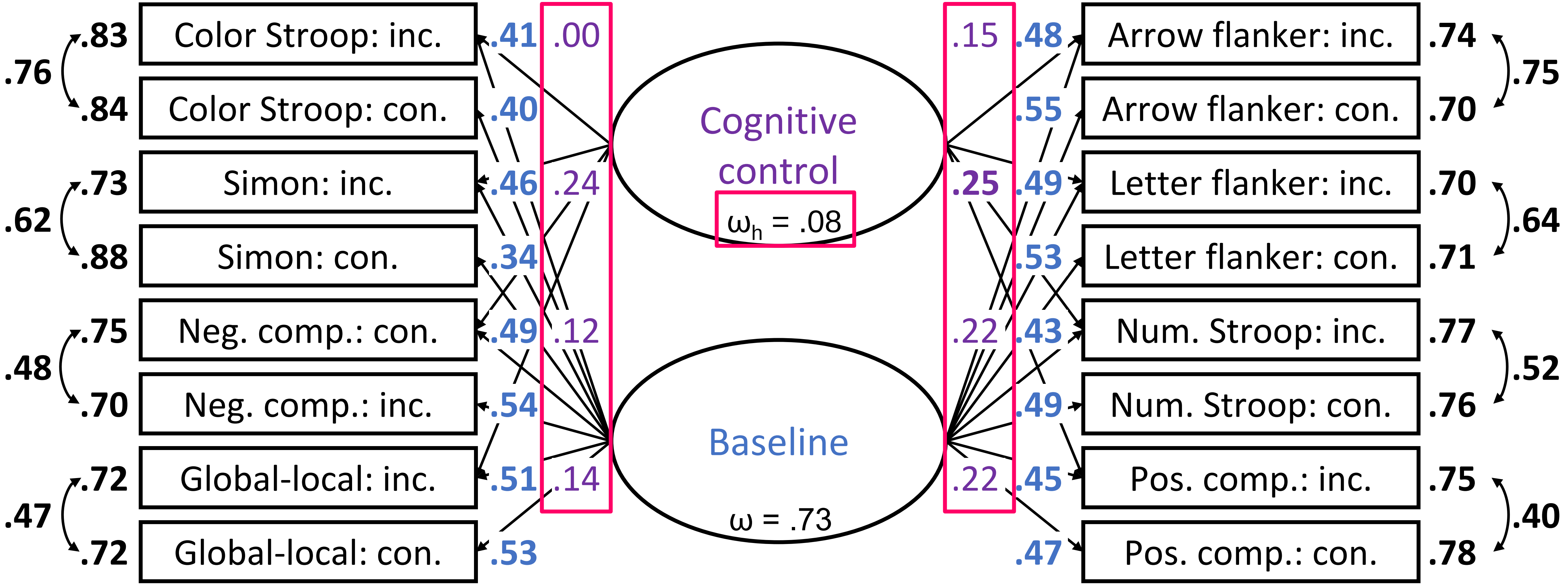


Note. Factor loadings were constrained to be positive. Bold = $p < .05$

CFI = 1, SRMR = .06

(see Rey-Mermet et al., 2021, *PsyArXiv*)

Structural equation modeling: Bifactor model



Note. Factor loadings were constrained to be positive. Bold = $p < .05$

CFI = 1, SRMR = .06

(see Rey-Mermet et al., 2021, *PsyArXiv*)

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- the difficulty of **isolating** **cognitive control** **from** **measurement error**

Conclusion

- **None of the methodological limitations** explains the difficulty of establishing **a psychometric construct of cognitive control**.
- This emphasizes the necessity of **rethinking cognitive control**.

Thanks to…

Henrik Singmann

Klaus Oberauer

Thank you for your attention!

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