2020-05-21 Lab meeting

Improving the reliability of Model-based decision-making estimates in the two-stage decision task with reaction-times and drift-diffusion modeling

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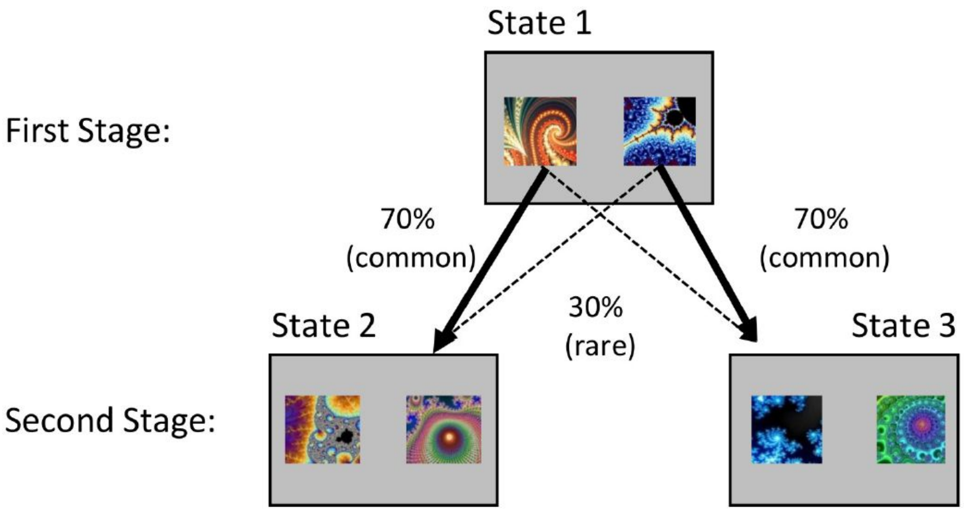
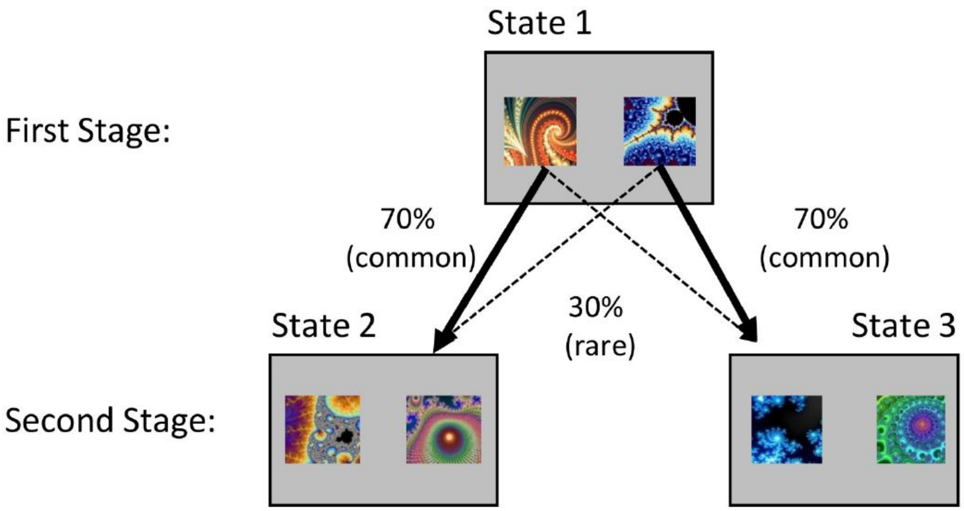
Contents

1. Two-Step Task



- ‘Gold standard’ for estimating MB, MF contributions to choice
- No task reliability estimates
- Does not use RT

1. Two-Step Task



Choice

RT

2. ‘Model-Basedness’ Estimation

	Process-Based Estimate		Model-Agnostic Estimate	
	RL only	RLDDM	MB-I	MB-II
Data Used	Choice	Choice+RT	Choice	RT
MB Estimate	w	w	RewardXTransition Interaction Effect	Transition Effect

(1)Process-Based Estimates

w-parameter I (RL-choice)

(1) Second stage Q-value update (SARSA-lambda)

$$Q^{MF}{}_{(a2,t+1)} = Q^{MF}{}_{(a2,t)} + \alpha(r_{(t)} - Q^{MF}{}_{(a2,t)})$$

(2) First stage Q-value update (SARSA-lambda)

$$Q^{MF}{}_{(a1,t+1)} = Q^{MF}{}_{(a1,t)} + \alpha\,(Q^{MF}{}_{(a2,t)} - Q^{MF}{}_{(a1,t)}) + \alpha\lambda(r_{(t)} - Q^{MF}{}_{(a2,t)})$$

$$Q^{MB}{}_{(a1,t)} = P(s_2|a_1) * \max(Q^{MF}{}_{(s2,t)}) + P(s_3|a_1) * \max(Q^{MF}{}_{(s3,t)})$$

$$Q^{net}{}_{(a1,t)} = (1 - w)Q^{MF}{}_{(a1,t)} + wQ^{MB}{}_{(a1,t)} + p \cdot Stay_{(a1,t)}$$

w-parameter I (RL-choice)

(3) Choice Rule: Softmax

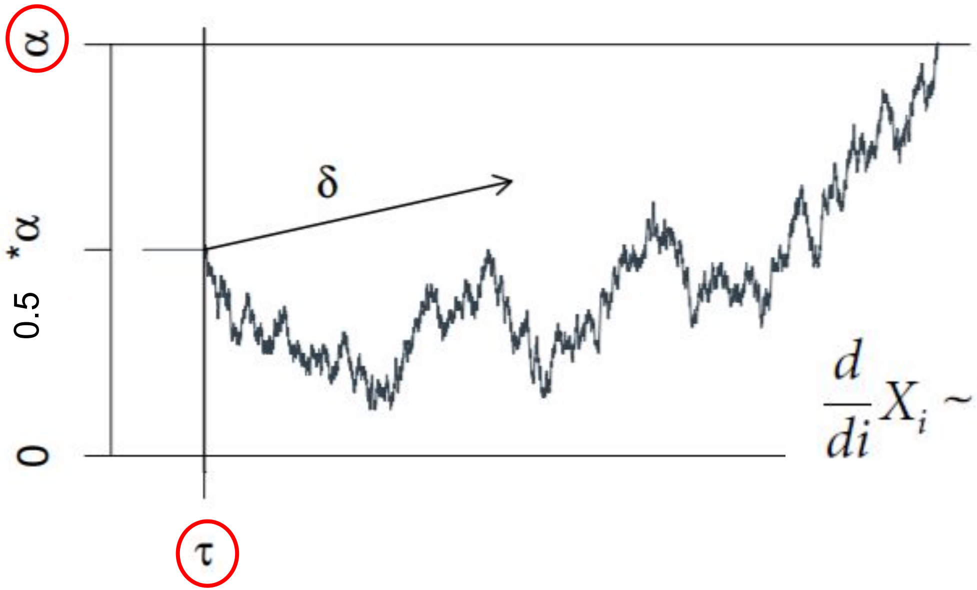
$$P(a1, t) = \frac{exp\left(\beta Q^{net}(a1, t)\right)}{\sum_{a'} exp(\beta Q^{net}(a', t))}$$

$$P(a2, t) = \frac{exp(\beta Q^{MF}(a2, t))}{\sum_{a'} exp(\beta Q^{MF}(a', t))}$$

: 5 or 7 parameters

w-parameter II (RLDDM-choice & RT)

(3)’ Choice Rule: (Wiener) drift diffusion model



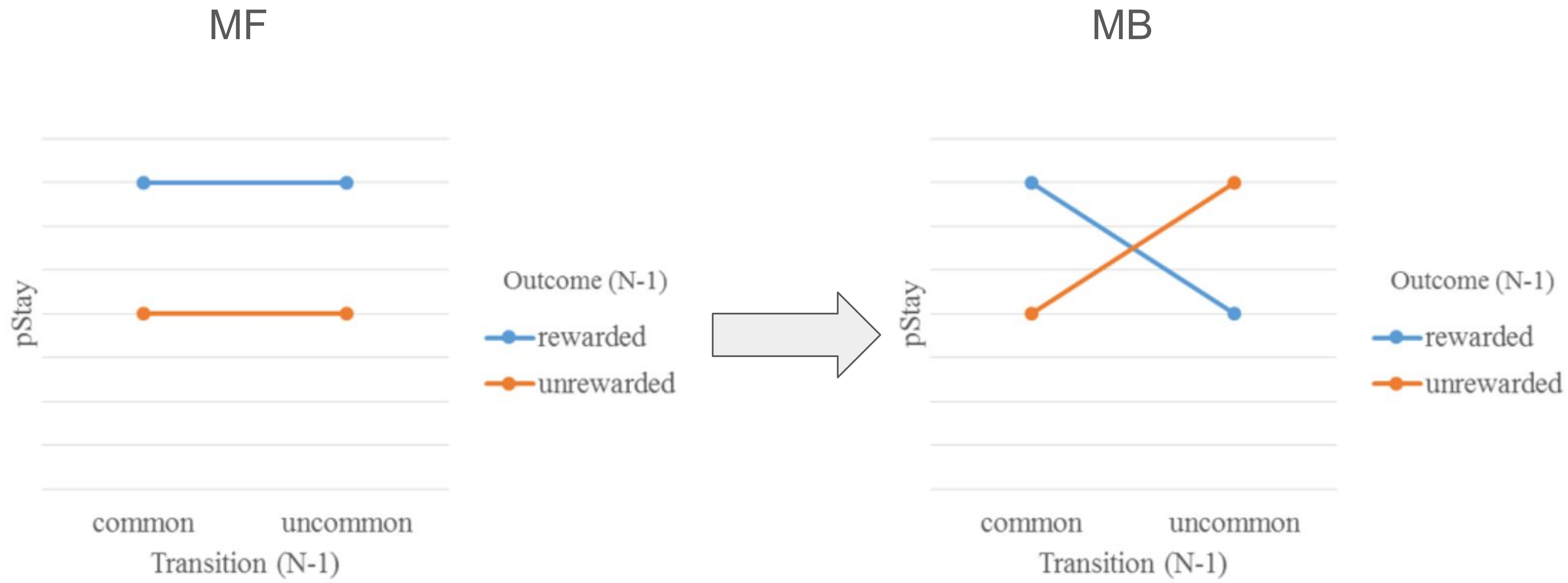
$$\frac{d}{di}X_i \sim Normal(\delta, s^2)$$

$$\frac{d}{di}X_i \sim Normal(b(Q(a,t) - Q(a',t)), s^2)$$

(Image from: Wabersich & Vanderkerckhove (2014))

(2)Model-Agnostic Estimates

MB-I (choice)


MF
pStay
common
uncommon
Transition (N-1)
Outcome (N-1)
rewarded
unrewarded
MB
pStay
common
uncommon
Transition (N-1)
Outcome (N-1)
rewarded
unrewarded

MB-I (choice)

(1)Individual Estimate

	common transition effect on rewarded trials	−	common transition effect on unrewarded trials	=	**MB-I**
MB agent	ΔpStay>0		ΔpStay<0		>0
MF agent	ΔpStay = 0		ΔpStay = 0		=0

$$\text{Rewarded} = P(Y_{stay\,(t+1)}|X_{transition\,(t)} = 0, X_{reward\,(t)} = 1) - P(Y_{stay\,(t+1)}|X_{transition\,(t)} = 1, X_{reward\,(t)} = 1)$$

$$\text{Unrewarded} = P(Y_{stay\,(t+1)}|X_{transition\,(t)} = 0, X_{reward\,(t)} = 0) - P(Y_{stay\,(t+1)}|X_{transition\,(t)} = 1, X_{reward\,(t)} = 0)$$

$$\text{MB} - \text{I}_{(choice)} = \text{Rewarded} - \text{Unrewarded}$$

MB-I (choice)

(2) Hierarchical estimate

- Mixed-effect logistic regression
- MB-I: **‘individual slope’** of transition X reward interaction

$$P(Y_{\mathrm{stay}(t+1)}) \sim \boxed{\mathrm{Transition}_{(t)} * \mathrm{Reward}_{(t)}} + \boxed{(\mathrm{Transition}_{(t)} * \mathrm{Reward}_{(t)} \mid \mathrm{Subject})}$$

Fixed effect
(group prior constraint)

Random effect
(different for each subject)

=Transition(t) + Reward(t) + Transition(t)·Reward(t) +(~|Subject)

MB-II (RT)

(1)Individual Estimate

- MB-II>0 if model-based

$$MB - II_{(RT)} = mean(RT_2 | X_{transition(t)} = 1) - mean(RT_2 | X_{transition(t)} = 0)$$

(2)Hierarchical Estimate

- **<u>Individual Slope</u>** of Transition's Main Effect

$$RT_{2(t)} \sim \boxed{Transition_{(t)}} + \boxed{(Transition_{(t)} | Subject)}$$

3. Data Properties

1. Participants

- Kiddle et al. (2018): NSPN study

	Baseline	Follow-up1	**Follow-up2**
N	819	63	571
Mean age	18.85 yrs old	18.94 yrs old	20.33 yrs old
Mean time since baseline	0	6.53 months	17.75 months
# of trials in task	121	121	201

3. Data Properties

2. Model-based estimates

(1) **Process-based** fit estimate

- RL model : 7 parameters (separate α and β for first and second stage)
- DDM-RL model : 11 parameters (separate a, b, τ, α for first and second stage)

	RL		DDM-RL	
# of parameters	5	7	8	11
BIC(baseline)	134738.6	134194.7	113648.1	104220.4
BIC(follow-up)	216901.9	215646	174546	162964.3

3. Data Properties

2. Model-based estimates

(2) **Model-agnostic** effect size

- $\eta^2 = SS_{(effect)}/SS_{(Total)}$

- MB-I (choice): $\eta^2 = SS_{(reward x transition)}/SS_{(Total)} = .251$

- MB-II (RT): $\eta^2 = SS_{(transition)}/SS_{(Total)} = .673$

4. Results - **(1) Relationship between parameters**

Table 1. Correlation estimates describing the relationship between the different model-based estimates.

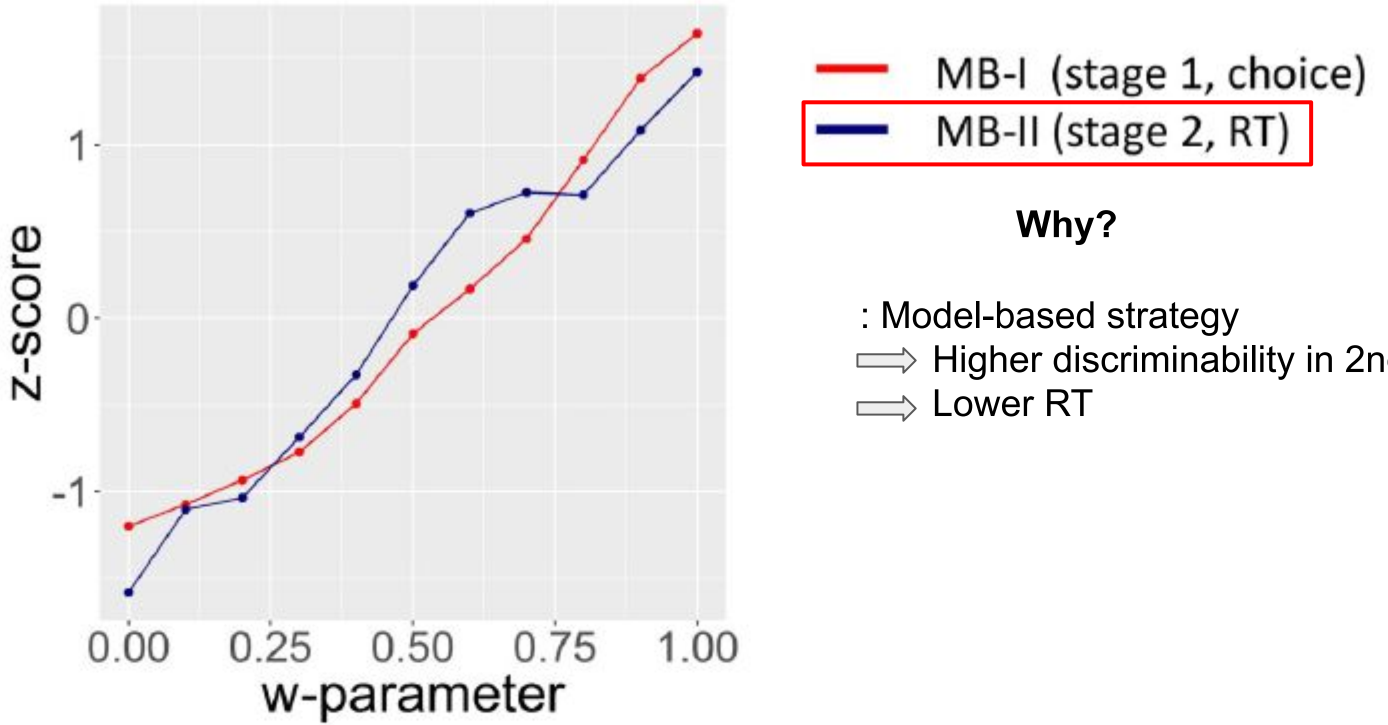
	MB-I (choice)	MB-II (RT)
Individual scores:		
MB-II (RT)	.53[a] (.47-.59)	.
w-parameter (RL)	.38 (.30-.45)	.26 (.18-.34)
w-parameter (DDM-RL)	.41 (.33-.47)	.24 (.16-.32)
Hierarchical scores:		
MB-II (RT)	.61[a] (.56-.66)	.
w-parameter (RL)	.31[b] (.23-.38)	.33[b] (.26-.41)
w-parameter (DDM-RL)	.37[b] (.30–44)	.36[b] (.29-.43)

Note.

[a]Pearson correlation estimate.

[b]Spearman rank estimate

4. Results - **(1) Relationship between parameters**



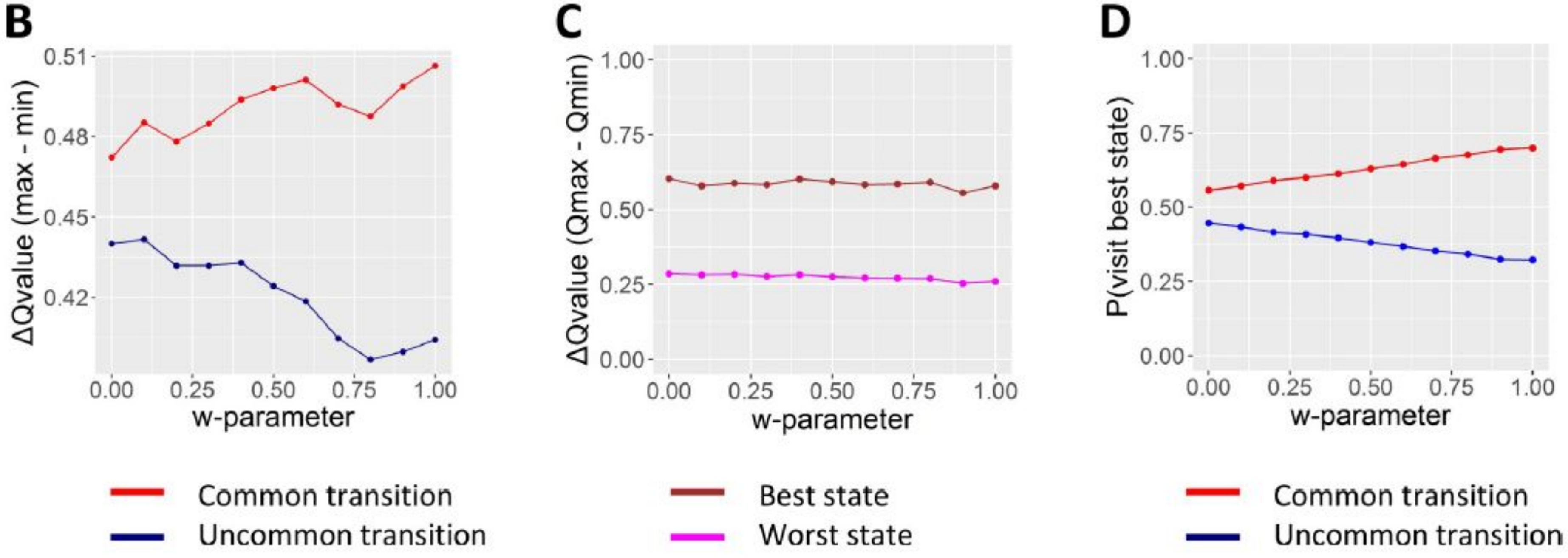
Why?

: Model-based strategy

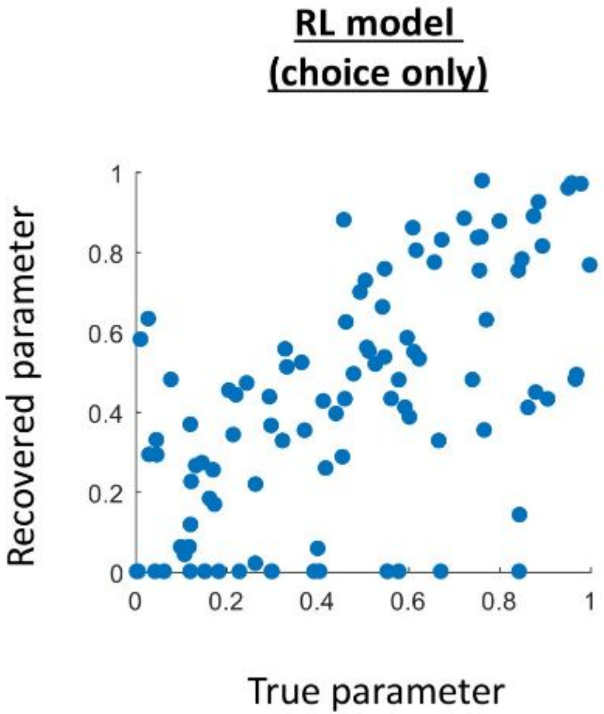
⇨ Higher discriminability in 2nd stage

⇨ Lower RT

4. Results - **(1) Relationship between parameters**



4. Results - **(2) Parameter Recovery**



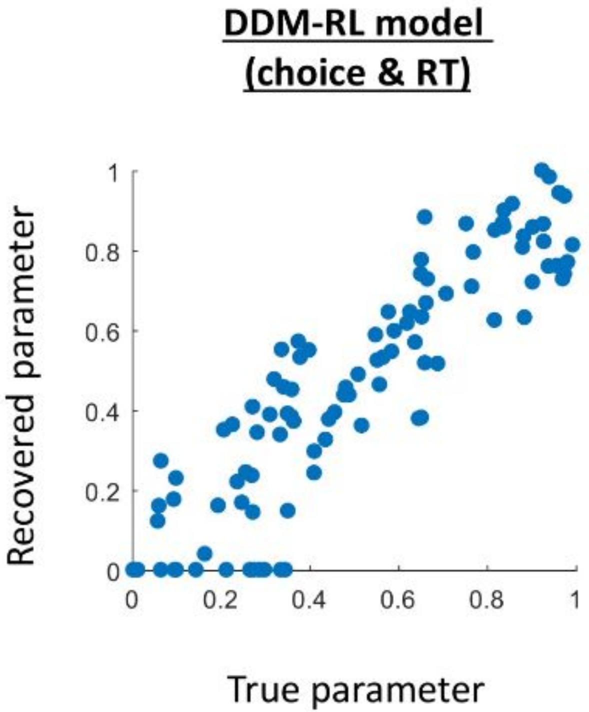


Fig 4. (**A/B**) Scatter plots for true compared to recovered w-parameter (estimating model-based/free trade off). Results show a better correlation for DDM-RL (panel B; modeling choice & RT, r = .9) compared with an RL (choice only) model previously reported in the literature (panel A, r = .62).

4. Results - **(2) Parameter recovery**

Table 2. Spearman's correlation estimating the relationship between the true and recovered parameters.

		Trials in the analysis			
		200	**500**	**1000**	**5000**
RL model (choice)	α_1	.54	.62	.68	.92
	α_2	.95	.98	.99	.99
	λ	.53	.71	.71	.88
	w	**.61**	**.69**	**.82**	**.97**
	p	.82	.90	.91	.97
	β_1	.82	.90	.93	.98
	β_2	.89	.96	.98	.99
DDM-RL model (choice & RT)	α_1	.68	.72	.84	.94
	α_2	.99	.99	.99	.99
	λ	.58	.75	.83	.92
	w	**.90**	**.95**	**.96**	**.99**
	p	.91	.94	.97	.99
	b_1	.93	.93	.99	.99
	a_1	.93	.98	.99	.99
	τ_1	.99	.99	.99	.99
	b_2	.99	.99	.99	.99
	a_2	.97	.99	.99	.99
	τ_2	.99	.99	.99	.99

4. Results - **(2) Internal consistency (agnostic)**

Table 3. Psychometric properties for model-based estimates.

		Internal consistency (201 trials)
MB-I (choice)	Individual scores	.52[c] (.45–58)
	Hierarchical scores	.81[c] (.78-.84)
MB-II (RT)	Individual scores	.87[c] (.85-.90)
	Hierarchical scores	.87[c] (.85-.89)
Latent score (choice & RT)		.
w-parameter (RL model)	Individual scores	.
	Hierarchical scores	.
w-parameter (DDM-RL model)	Individual scores	.
	Hierarchical scores	.

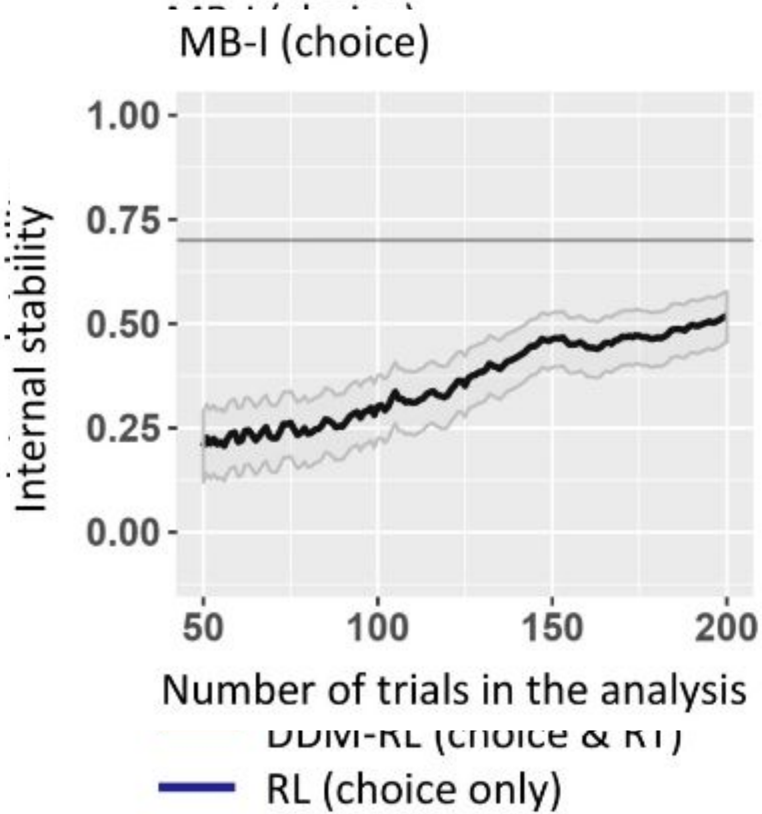
[a]Pearson correlation estimate.

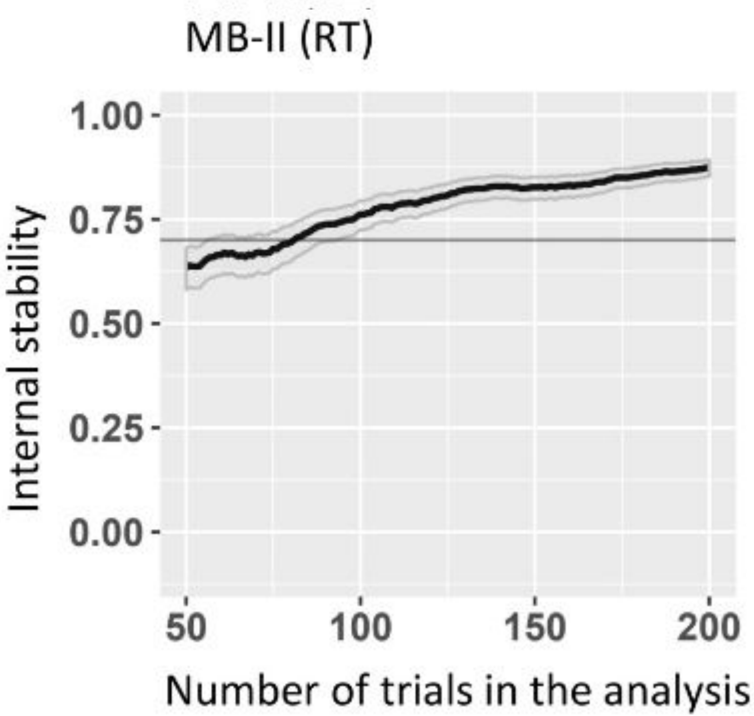
[b]Spearman rank correlation estimate.

[c]Spearman-Brown corrected Pearson correlation estimate.

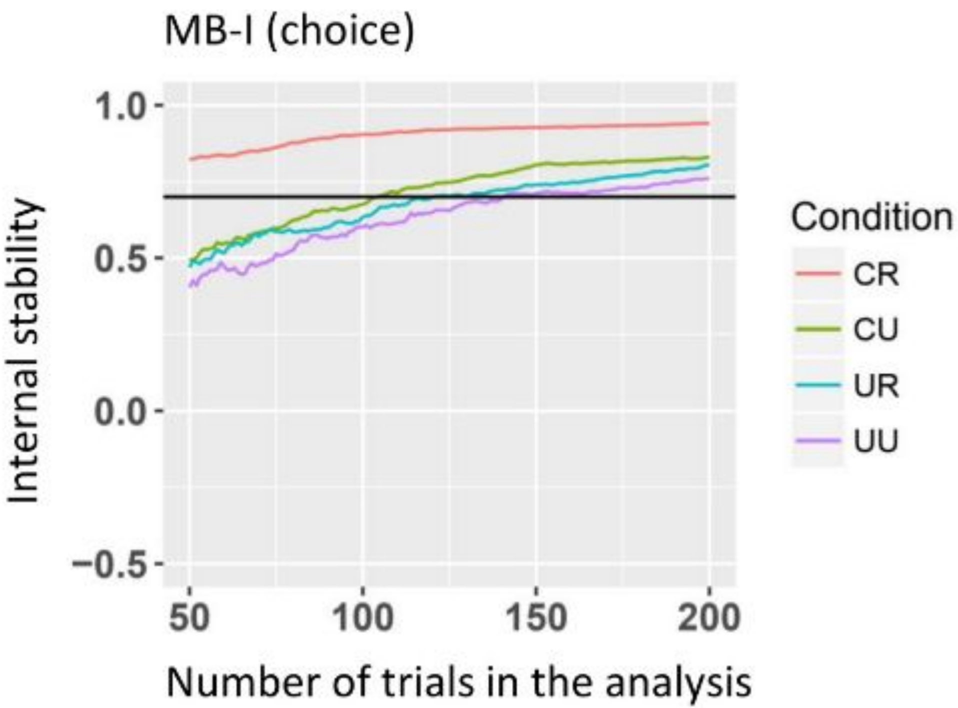
Estimates in brackets represent 95% confidence intervals.

4. Results - **(2) Internal consistency (agnostic)**





4. Results - **(2) Internal consistency (agnostic)**



4. Results - **(3) Temporal stability**

Table 3. Psychometric properties for model-based estimates.

		Temporal stability
MB-I (choice)	Individual scores	.28[a] (.20-.36)
	Hierarchical scores	.40[a] (.32-.46)
MB-II (RT)	Individual scores	.33[a] (.25-.40)
	Hierarchical scores	.33[a] (.25-.40)
Latent score (choice & RT)		.75[a] (.71-.78)
w-parameter (RL model)	Individual scores	.16 [b] (.07-.24)
	Hierarchical scores	.21[b] (.13-.29)
w-parameter (DDM-RL model)	Individual scores	.20[b] (.12-.28)
	Hierarchical scores	.14[b] (.05-.22)

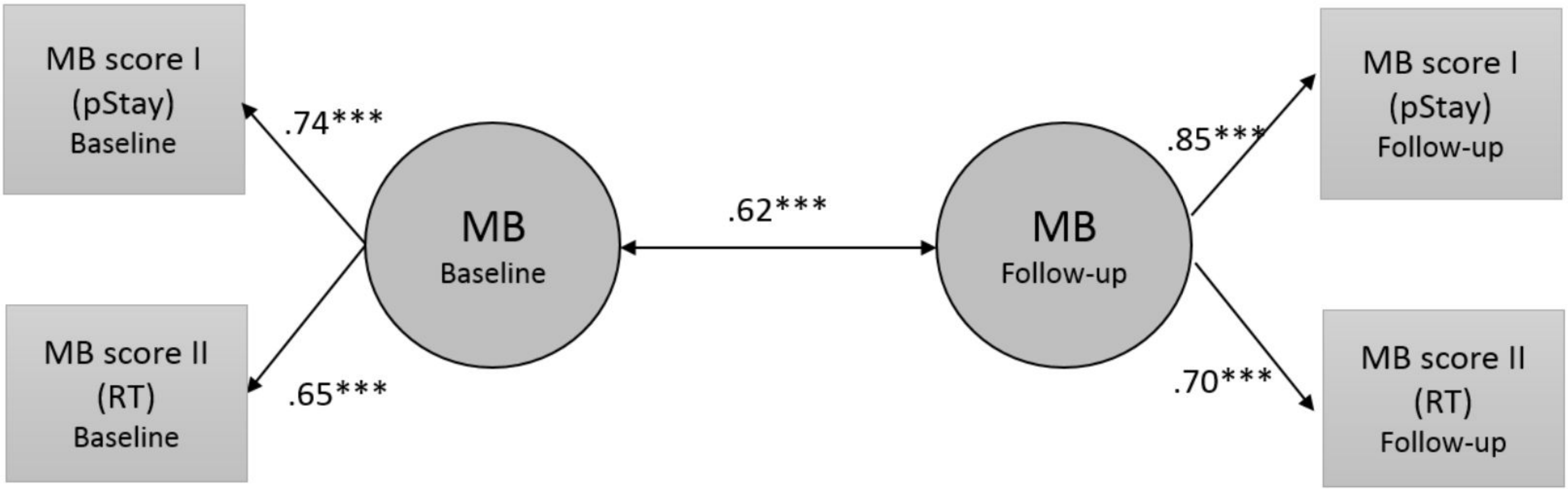
[a]Pearson correlation estimate.

[b]Spearman rank correlation estimate.

[c]Spearman-Brown corrected Pearson correlation estimate.

Estimates in brackets represent 95% confidence intervals.

4. Results - **(3) Temporal stability**



4. Results - **(4) Group-level effect**

<Power Analysis>

- Power = P(reject NH | NH is false)
- effect size, sample size, experiment length ⇨ simulate, MANOVA

Table 4. Statistical power (percent of studies that rejected the null hypothesis, given an effect exists) for a between group design (control vs. experiment). Table values show the chance of finding a statistically significant between group effect as a function of true effect-size, sample-size and number of trials in the experiment.

		200 trials	500 trials	1000 trials
Small effect (Cohen's d = .2)	30 participants	4.5%	5.8%	7.5%
	100 participants	6.2%	9%	8.2%
	500 participants	14.1%	24%	28.2%
Medium effect (Cohen's d = .5)	30 participants	7%	7%	7.9%
	100 participants	11%	15%	15.1%
	500 participants	52.8%	64%	67%
Large effect (Cohen's d = .8)	30 participants	11.5%	10.9%	13%
	100 participants	31.5%	30.3%	37.8%
	500 participants	94.7%	90.7%	96.9%

5. Discussion

1.RLDDM's characteristics

(1)RLDDM's w-parameter shows close relationships with model-agnostic measures

(2)Improved parameter recovery, stable model-agnostic estimates

(3)Provides link between MB-I and MB-II

(4)Low temporal stability

5. Discussion

2. Other factors affecting stability

(1)Model-agnostic estimate for second-stage RT

(2)Hierarchical estimation

(3)Latent factor analysis

3. What to do?

(1)Use both choice and RT

(2)More trials

Thank you :)