Supplementary information for "How should we measure exploration?"

Tables

Model	χ^2	df	p	CFI	RMSEA [90% CI]	SRMR	AIC	BIC
2 Factors	5.59	5	0.35	1	0.03 [0, 0.11]	0.02	2722	2772
1 Factor	42.3	6	0	0.87	0.19 [0.14, 0.24]	0.08	2756	2804

Table 1. Model comparison for the two measurement models representing exploration as one factor or as two factors (i.e., value-guided and directed).

Model	χ^2	df	p	CFI	RMSEA [90% CI]	SRMR	AIC	BIC
4 Factors	12.36	10	0.26	0.995	0.037 [0, 0.09]	0.03	2008	2065

Table 2. Fit indices for the measurement model based on the questionnaire scores.

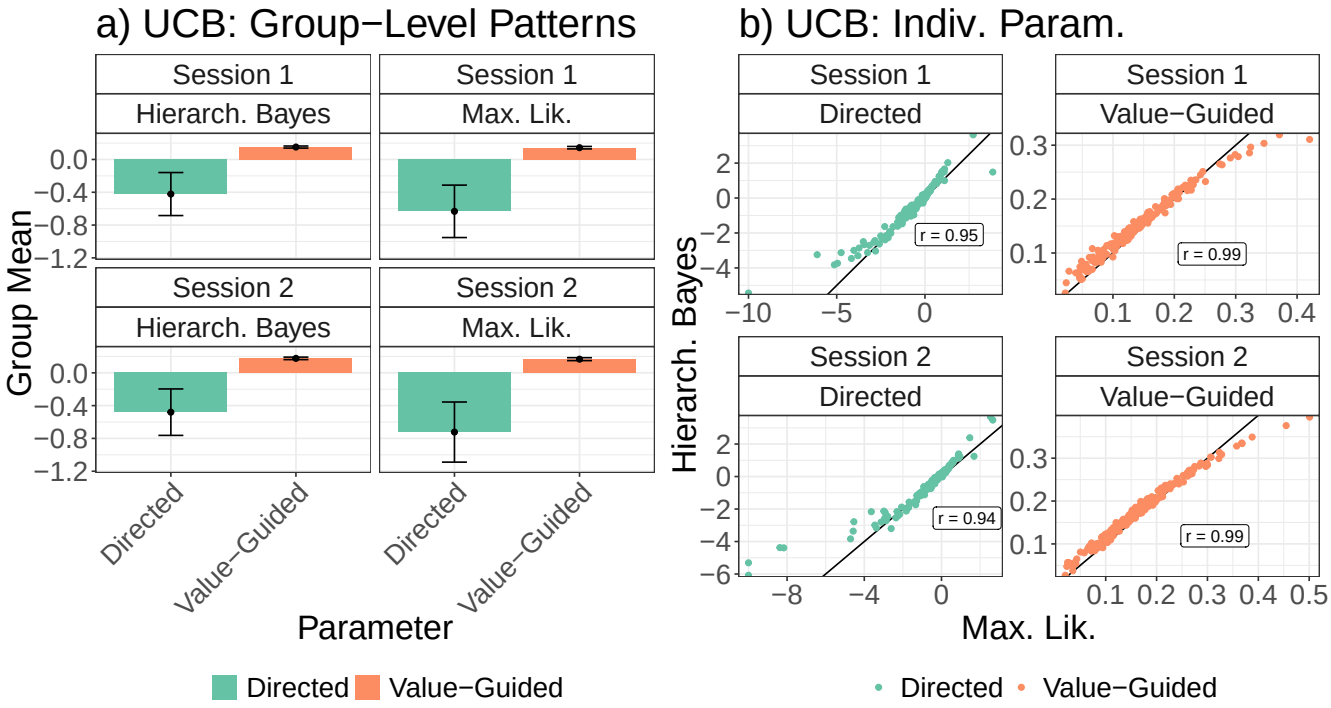
Table 3. Test-retest reliability of hierarchical vs subject-level estimates of the parameters in the Horizon task

method	predictor	horizon	correlation
hierarchical	value-guided	long	0.57
hierarchical	value-guided	short	0.52
hierarchical	directed	long	0.17
hierarchical	directed	short	0.51
subject-level	value-guided	long	0.38
subject-level	value-guided	short	0.16
subject-level	directed	long	0.01
subject-level	directed	short	0.16

Table 4. Out-of-sample prediction for the hierarchical and the subject-level implementation of the model in the Horizon task. We predicted session two data using parameters fit on session one data.

method	Horizon	Log Likelihood
hierarchical	short	$-1,988.125$
hierarchical	long	$-2,137.137$
subject-level	short	$-2,884.124$
subject-level	long	$-2,492.672$

Figures



c) Reliability

	Parameter	Method	Reliability
1	Directed	hcb	0.52
2	Directed	ml	0.40
3	Value−Guided	hcb	0.48
4	Value−Guided	ml	0.43

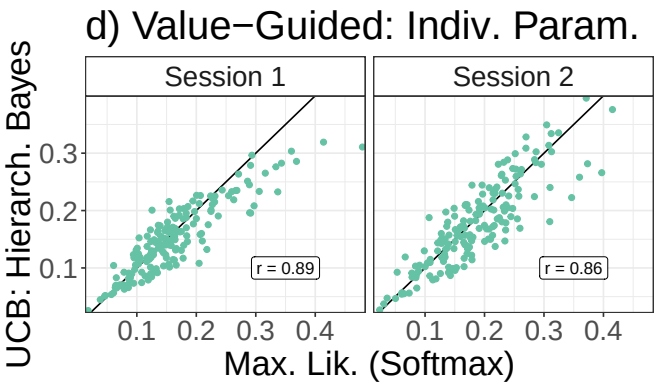


Figure 1. Panel a) shows that the group-level pattern was the same between the two methods. Panel b) shows that the correlation of the model parameters between the two methods was extremely high, and that the hierarchical Bayesian method pulled outliers, as calculated with ML, closer to the overall group mean (i.e., shrinkage). Panel c) shows that the reliabilities of the model parameters were larger in the hierarchical Bayesian method than in the ML method. Panel d) shows a high correlation between value-guided exploration in the softmax model (i.e., only value-guided exploration) and in the UCB model (i.e., value-guided and directed exploration)

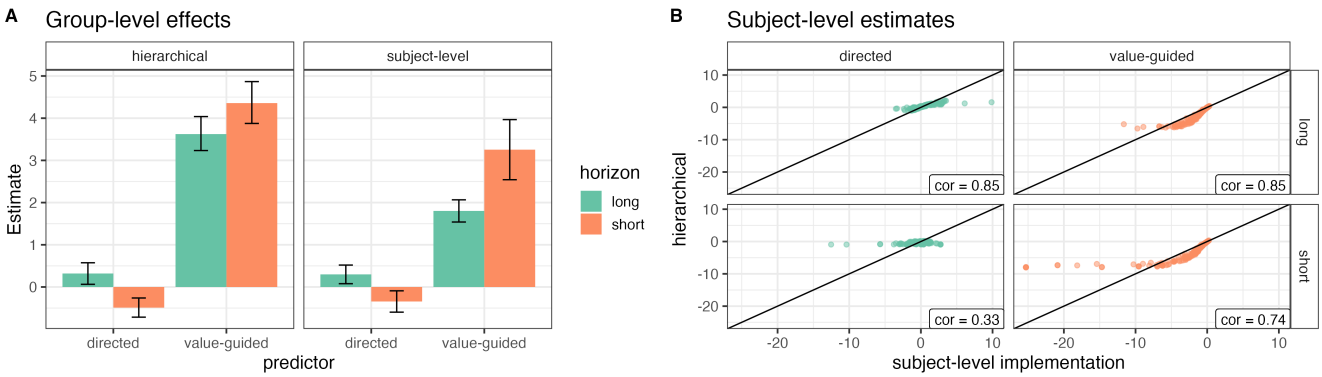


Figure 2. **A:** The patterns of group-level effects remain qualitatively unchanged when replacing the classic subject-level modeling approach with a hierarchical Bayesian approach. **B:** Similarly, the parameter estimates from the classic subject-level modeling approach are highly correlated with the parameter estimates from the hierarchical Bayesian approach. The latter does however yield a much narrower distribution of estimates by avoiding extreme outliers.

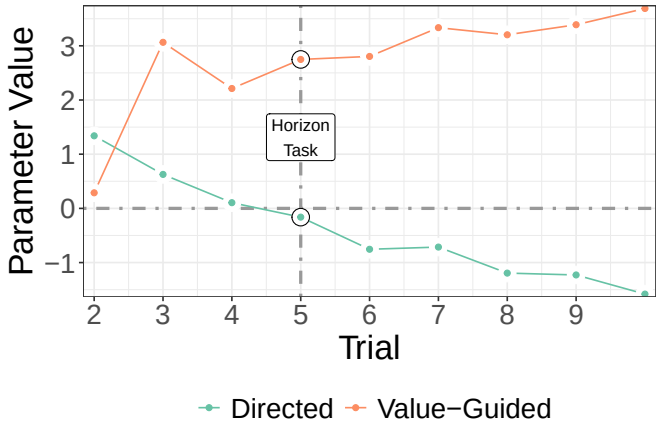


Figure 3. Parameter values for value-guided and directed exploration plotted over trials when a hierarchical model is separately fitted to the choices in trials 2 - 10 in the Two-armed bandit task. Trial 5 in the Two-armed bandit reflects the first free choice in the Horizon task.

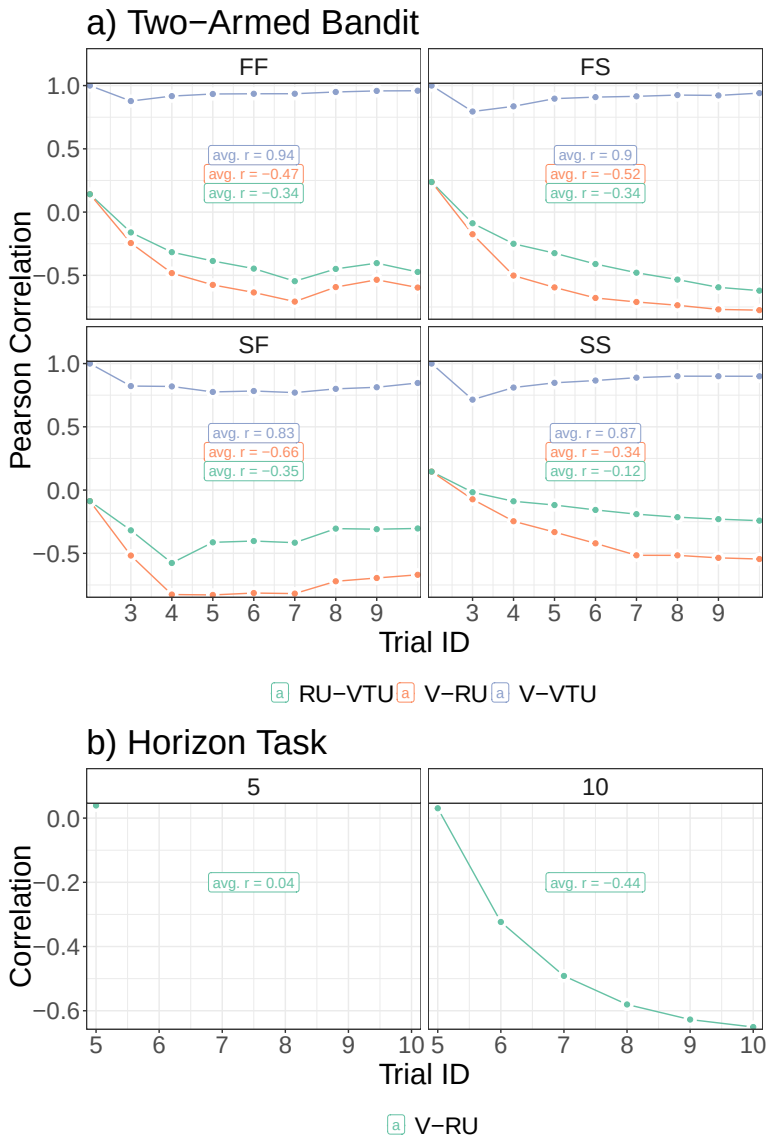


Figure 4. a) Correlations between differences in expected value (V), differences in uncertainties (RU), and differences in expected value divided by total uncertainty (VTU) in the Two-armed bandit tasks[?]. b) Correlations between value-guided exploration (V) and directed exploration (RU) in the Horizon task. The correlation between value-guided exploration and directed exploration in the Restless bandit task was -.19.