Accumulation is late and brief in preferential choice

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Take-home

In preferential choice information is acquired bit-by-bit over time

Over and above the attribute values, using the order in which attributes are acquired does not help predict choices

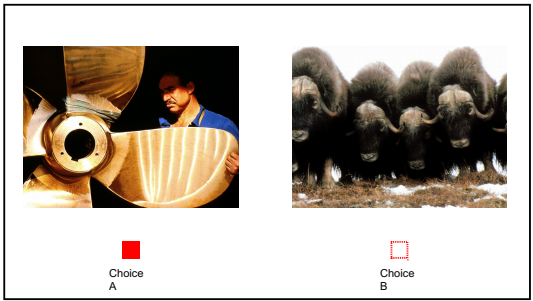
What does this mean for accumulator models? As all of the attribute values are not known until they have been fixated, this suggests that accumulation does not start until this point

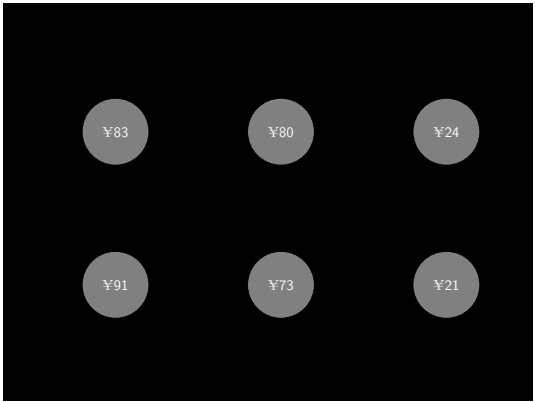
This implication is that almost all of the reaction time for a choice is not accumulation time

Accumulator Models

- Models such as decision field theory (Busemeyer & Townsend, 1993; Roe, Busemeyer, & Townsend, 2001)
- Leaky competing accumulators (Usher & McClelland, 2001)
- Poisson race model (Otter, Allenby, & Van Zandt, 2008)
- Attentional drift diffusion model (Krajbich, Armel, & Rangel, 2010)
- Associative accumulator model 14 (Bhatia, 2013)
- Multialternative linear ballistic accumulator model (Trueblood, Brown, & Heathcote, 2013)
- Multialternative decision by sampling (Noguchi & Stewart, 2018)

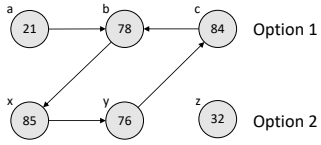
Four Experiments





An Example Trial

Fixation number	Value fixated	Values known					
		$\hat{V}_a$	$\hat{V}_b$	$\hat{V}_c$	$\hat{V}_x$	$\hat{V}_y$	$\hat{V}_z$
pre-fixation	+	50	50	50	50	50	50
1	21	21	50	50	50	50	50
2	78	21	78	50	50	50	50
3	85	21	78	50	85	50	50
4	76	21	78	50	85	76	50
5	84	21	78	84	85	76	50
6	78	21	78	84	85	76	50



Models I

Logistic regression framework: Log Odds(Choose A) $= \beta_0 + \beta_\Delta \Delta$

1. Value Difference:
$\Delta_{\text{VALUE}} = \frac{V_a+V_b+V_c}{3} - \frac{V_x+V_y+V_z}{3}$

2. Fixation Weighted:
$\Delta_{\text{WEIGHTED VALUE}} = \frac{1}{N}\left(\sum_{i\in a,b,c} f_i V_i - \sum_{j\in x,y,z} f_j V_j\right)$

3. Updating Value:
$\Delta_{\text{UPDATING VALUE}} = \frac{1}{N}\left(\sum_{n=1}^{N}\left[\frac{\hat{V}_a+\hat{V}_b+\hat{V}_c}{3} - \frac{\hat{V}_x+\hat{V}_y+\hat{V}_z}{3}\right]_n\right)$

where V_i is the value of attribute i,
f_i is the number of fixations to i (N in total)
$[\hat{V}_i]_n$ is what is known by fixation n about i

Models II

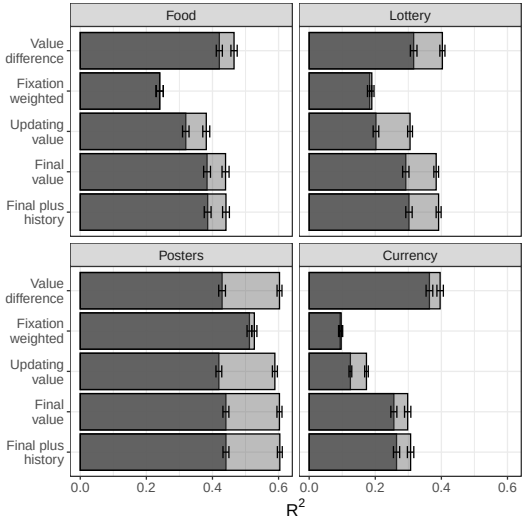
4. Final Value:
$\Delta_{\text{FINAL VALUE}} = \left[\frac{\hat{V}_a + \hat{V}_b + \hat{V}_c}{3} - \frac{\hat{V}_x + \hat{V}_y + \hat{V}_z}{3} \right]_{n=N}$

5. Final Plus History:
$\Delta_{\text{HISTORY}} = \Delta_{\text{FINAL VALUE}} + \sum_{i \in a,b,c,x,y,z} p_i (V_i - v)$

Attention: $A = \frac{T_a + T_b + T_c}{T_a + T_b + T_c + T_x + T_y + T_z}$

where V_i is the value of attribute i,
f_i is the number of fixations to i (N in total)
$[\hat{V}_i]_n$ is what is known by fixation n about i,
p_i is the proportion of fixations for which the participant knew i
T_i is fixation time for i

Results I

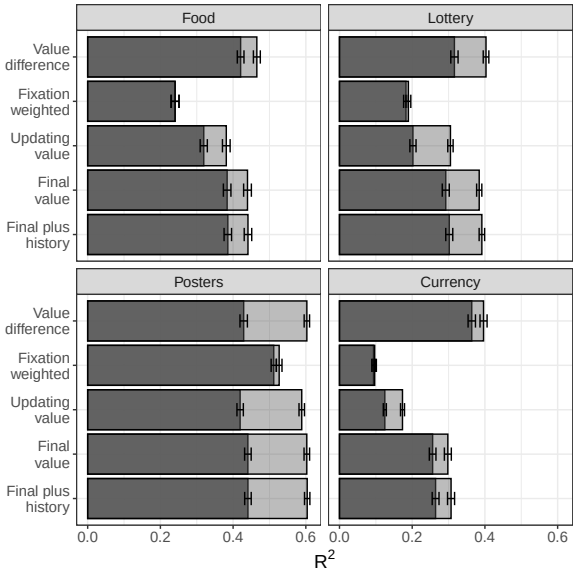

Food
Lottery
Posters
Currency
Value difference
Fixation weighted
Updating value
Final value
Final plus history
0.0
0.2
0.4
0.6
R^2

Results II

$$\Delta_{\text{UPDATING VALUE}} = \frac{1}{N}\left(\sum_{n=1}^{N}\left[\frac{\hat{V}_a+\hat{V}_b+\hat{V}_c}{3} - \frac{\hat{V}_x+\hat{V}_y+\hat{V}_z}{3}\right]_n\right)$$

$$\Delta_{\text{FINAL VALUE}} = \left[\frac{\hat{V}_a+\hat{V}_b+\hat{V}_c}{3} - \frac{\hat{V}_x+\hat{V}_y+\hat{V}_z}{3}\right]_{n=N}$$

- The final value model explains more variance than the updating value model
- That is, model fits worsen when they assume that the drift rate value is updated as new information is learned

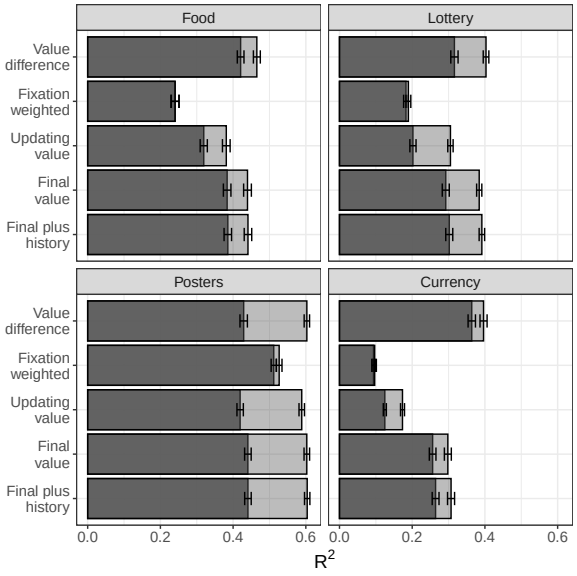


Results III

$$\Delta_{\text{FINAL VALUE}} = \left[\frac{\hat{V}_a+\hat{V}_b+\hat{V}_c}{3} - \frac{\hat{V}_x+\hat{V}_y+\hat{V}_z}{3}\right]_{n=N}$$

$$\Delta_{\text{HISTORY}} = \Delta_{\text{FINAL VALUE}} + \sum_{i\in a,b,c,x,y,z} p_i(V_i - v)$$

- In support, the final value plus history model accounts for no more variance than the final value (alone) model
- In other words, adding in information about when an attribute value was acquired does not improve model performance

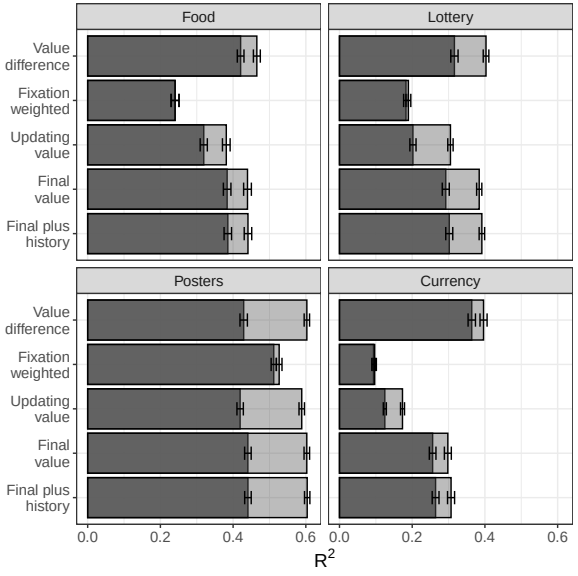


Results IV

$$\Delta_{\text{FINAL VALUE}} = \left[\frac{\hat{V}_a+\hat{V}_b+\hat{V}_c}{3} - \frac{\hat{V}_x+\hat{V}_y+\hat{V}_z}{3}\right]_{n=N}$$

$$\Delta_{\text{WEIGHTED VALUE}} = \frac{1}{N}\left(\sum_{i\in a,b,c} f_i V_i - \sum_{j\in x,y,z} f_j V_j\right)$$

- In three of the four experiments, the final value model explains more variance than the fixation weighted model.
- That is, assuming that evidence is only accumulated based upon the currently attended information makes the model fit worse.

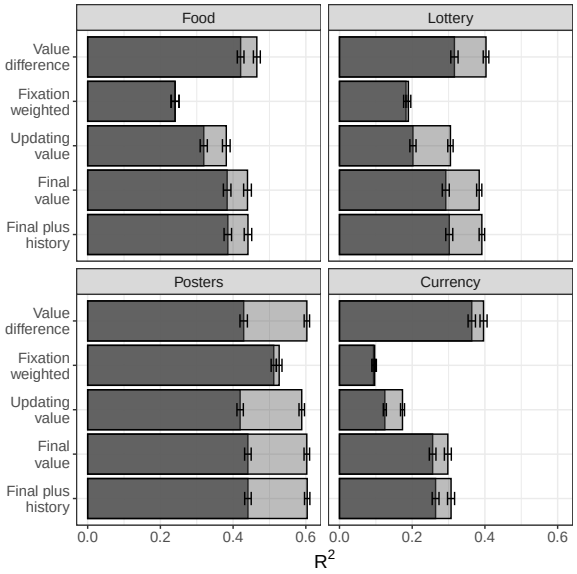


Results V

$$\Delta_{\text{FINAL VALUE}} = \left[\frac{\hat{V}_a+\hat{V}_b+\hat{V}_c}{3} - \frac{\hat{V}_x+\hat{V}_y+\hat{V}_z}{3}\right]_{n=N}$$

$$\Delta_{\text{WEIGHTED VALUE}} = \frac{1}{N}\left(\sum_{i\in a,b,c} f_i V_i - \sum_{j\in x,y,z} f_j V_j\right)$$

- The fixation weighted model explains more variance than the final value model for posters
- The fixation weighted model captures a large main effect of attention using its attention-by-value interaction

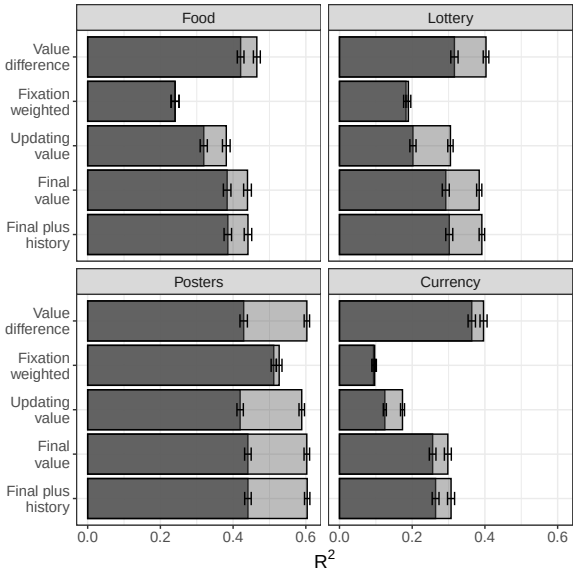


Results VI

$$\Delta_{\text{VALUE}} = \frac{V_a+V_b+V_c}{3} - \frac{V_x+V_y+V_z}{3}$$

$$\Delta_{\text{FINAL VALUE}} = \left[\frac{\hat{V}_a+\hat{V}_b+\hat{V}_c}{3} - \frac{\hat{V}_x+\hat{V}_y+\hat{V}_z}{3}\right]_{n=N}$$

- The value difference and final value model accounts for similar amounts of variance
- On view-all trials (the vast majority) the value difference model prediction *is* the final value model prediction.



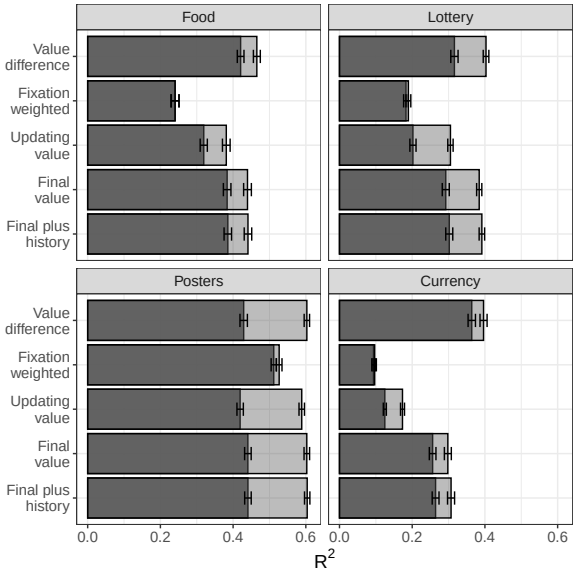
Results VII

$$\Delta_{\text{VALUE}} = \frac{V_a+V_b+V_c}{3} - \frac{V_x+V_y+V_z}{3}$$

$$\Delta_{\text{WEIGHTED VALUE}} = \frac{1}{N}\left(\sum_{i\in a,b,c} f_i V_i - \sum_{j\in x,y,z} f_j V_j\right)$$

$$\Delta_{\text{UPDATING VALUE}} = \frac{1}{N}\left(\sum_{n=1}^{N}\left[\frac{\hat{V}_a+\hat{V}_b+\hat{V}_c}{3} - \frac{\hat{V}_x+\hat{V}_y+\hat{V}_z}{3}\right]_n\right)$$

- The value difference model outperforms the fixation weighted model and the updating value model
- Using information about when attribute information is gained is not useful



Conclusion

Across four experiments the best performing models are ones which ignore the time when information is acquired

This has serious implications for accumulation-based models of value-based choice

We are forced to a strong conclusion: If adding knowledge about when information becomes available to evidence accumulation models makes their fit worse, we must conclude that, if there is an accumulation process, it does not begin until about the time the final fixation is made

Thus most of the reaction time is not accumulation time

	RT (ms)	t_0 (ms)	DDM Accumulation time (ms)	Our estimation Best split	Our estimation Accumulation time (ms)	Discrepancy
Food	2210	532	1678	1	242	65%
Posters	3514	897	2617	3	792	52%
Lottery	6516	1885	4631	3	753	60%
Currency	14574	2357	12217	1	385	81%

The *discrepancy* is the fraction of the trial on which the two approaches disagree about whether accumulation is taking place

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