

Multinomial Processing Tree Models of Recognition Memory

Joachim Vandekerckhove and Michael Lee

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 - e.g., discrete decisions rather than continuous response times
- MPTs make assumptions about how the different categories of behavior could be generated, in terms of probabilistic processes controlled by underlying psychological variables

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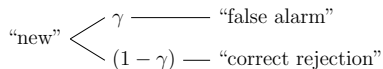
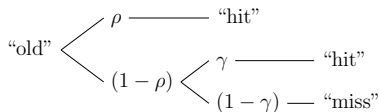
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- Behavior can be summarized in terms of four counts

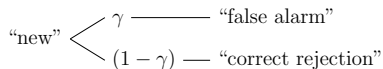
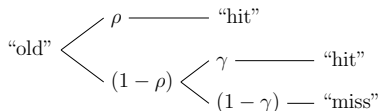
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One-High Threshold Model



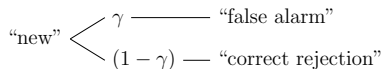
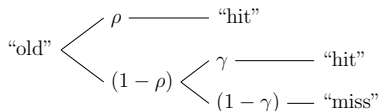
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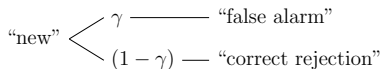
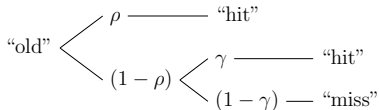
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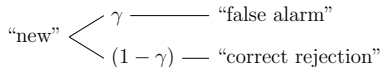
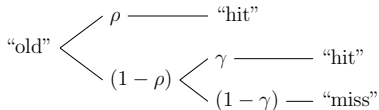
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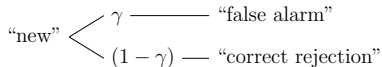
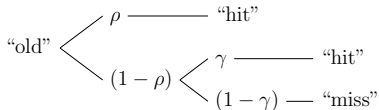
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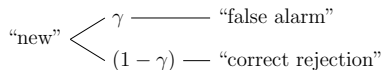
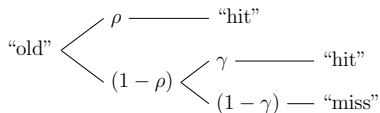
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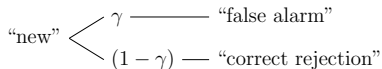
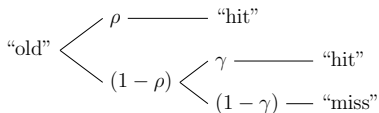
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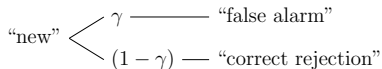
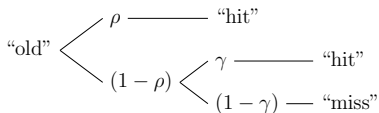
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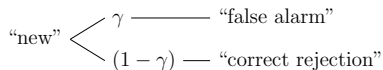
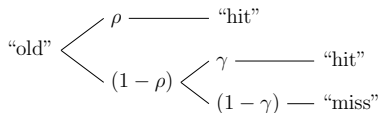
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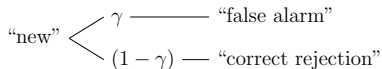
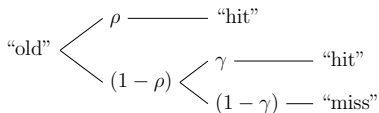
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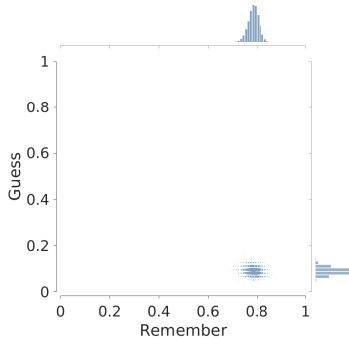
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 - amyloid positivity is thought to be a pre-symptomatic indicator of Alzheimer’s disease

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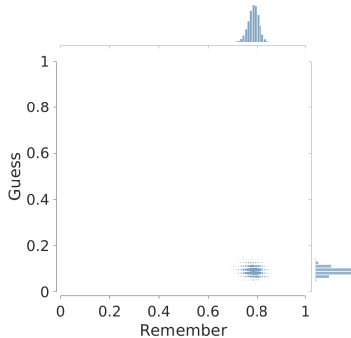
Amyloid Status	Hits	False Alarms
positive	8	4
negative	12	1
negative	14	0
positive	9	4
...

Amyloid Negative inferences



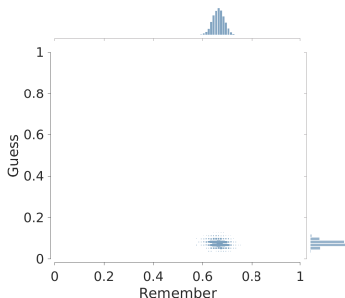
- The figure shows the joint and marginal posterior distributions for the remembering and guessing parameters

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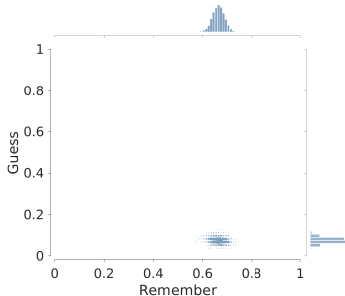
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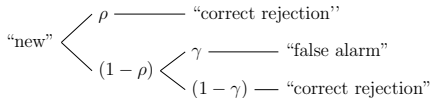
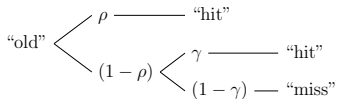
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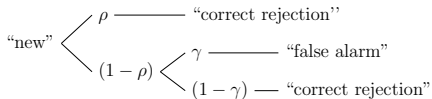
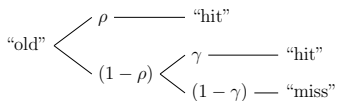
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- Very similar guessing behavior to amyloid negative group, but lower probability of remembering

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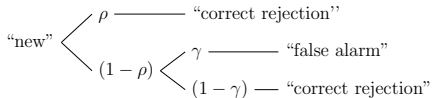
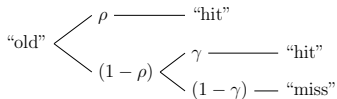
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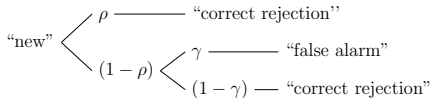
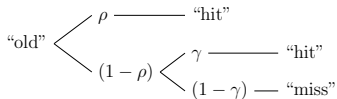
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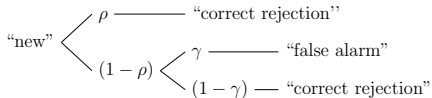
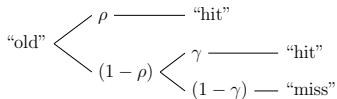
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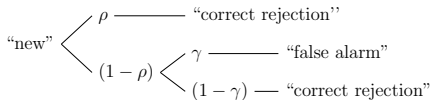
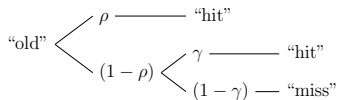
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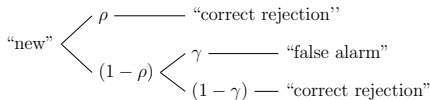
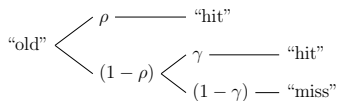
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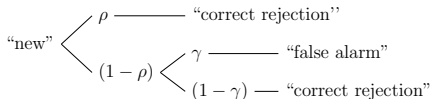
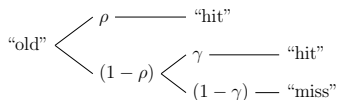
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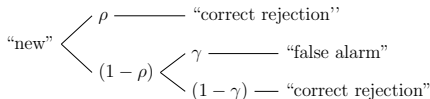
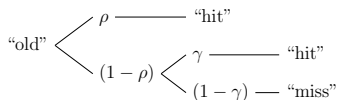
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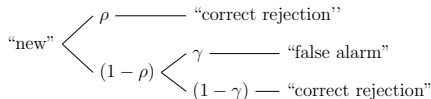
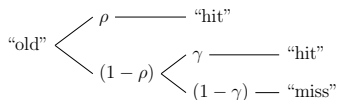
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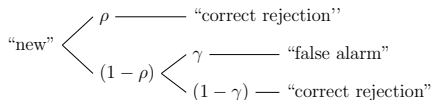
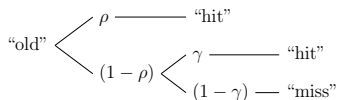
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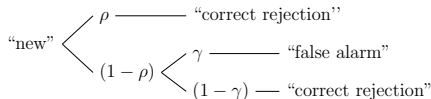
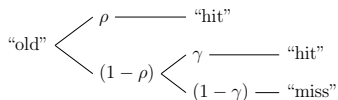
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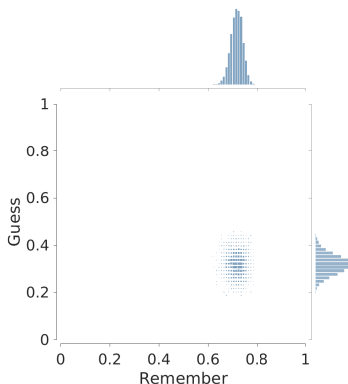
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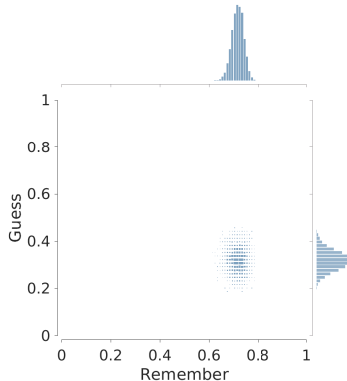
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 - By explicitly remembering the item was not on the list, or by guessing "old"
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 - $\theta^h = \rho + (1 - \rho) \gamma$
 - $\theta^f = (1 - \rho) \gamma$

Amyloid negative inferences



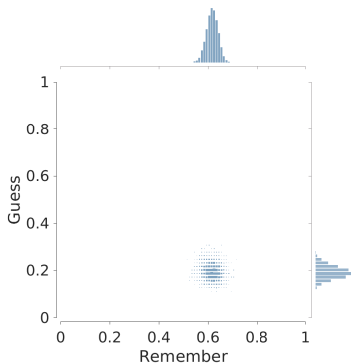
- The figure shows the joint and marginal posterior distributions for the remembering and guessing parameters

Amyloid negative inferences



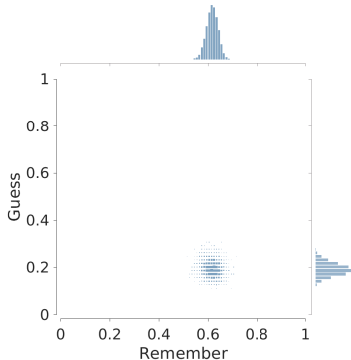
- The figure shows the joint and marginal posterior distributions for the remembering and guessing parameters
- Patients remember around 70-80% of the items, and guess “old” about 30% of the time when they do not remember

Amyloid positive inferences



- Patients remember around 60% of the items, and guess “old” about 20% of the time when they do not remember

Amyloid positive inferences



- Patients remember around 60% of the items, and guess “old” about 20% of the time when they do not remember
- The remembering rate is lower, and the guessing rate now also differs between the amyloid negative and positive groups

Key points

- MPT models make assumptions about how categorical observed behavior can be decomposed into sequences of probabilistic events

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- MPT models make assumptions about how categorical observed behavior can be decomposed into sequences of probabilistic events
- The one-high threshold and two-high threshold models of recognition memory are widely-used MPT models
- The inferences for the amyloid positivity data showed meaningful differences between the clinical groups, but the exact nature of the differences in remembering and guessing depends on the model

References

- Batchelder, W. H., and D. M. Riefer. 1980. "Separation of Storage and Retrieval Factors in Free Recall of Clusterable Pairs." *Psychological Review* 87: 375–97.
- Bean, Jessica. 2011. "Rey Auditory Verbal Learning Test." *Encyclopedia of Clinical Neuropsychology*, 2174–75.
- Erdfelder, Edgar, Tina-Sarah Auer, Benjamin E Hilbig, André Aßfalg, Morten Moshagen, and Lena Nadarevic. 2009. "Multinomial Processing Tree Models: A Review of the Literature." *Zeitschrift für Psychologie/Journal of Psychology* 217: 108–24.