Associative learning changes multivariate neural signatures of visual working memory

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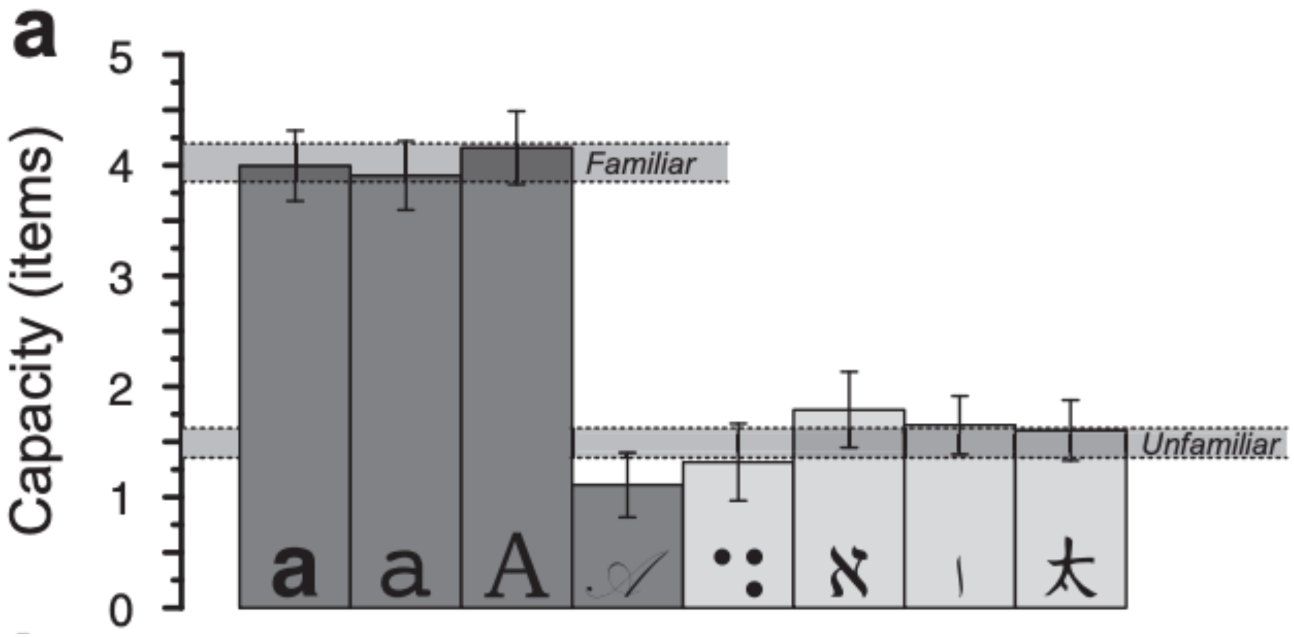
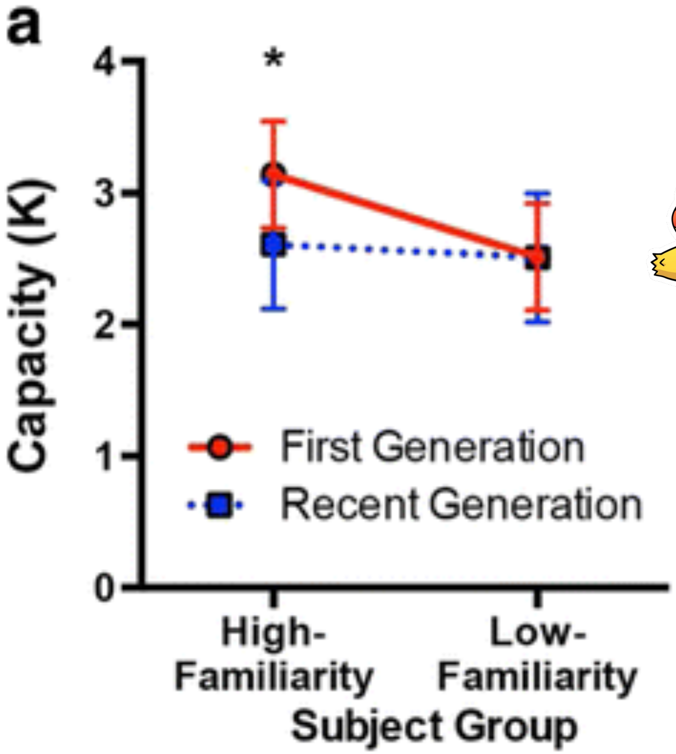
Working memory is aided by long-term memory

- A hallmark of our visual working memory system is its sharp capacity limit
- But this capacity limit can be overcome with familiarity:

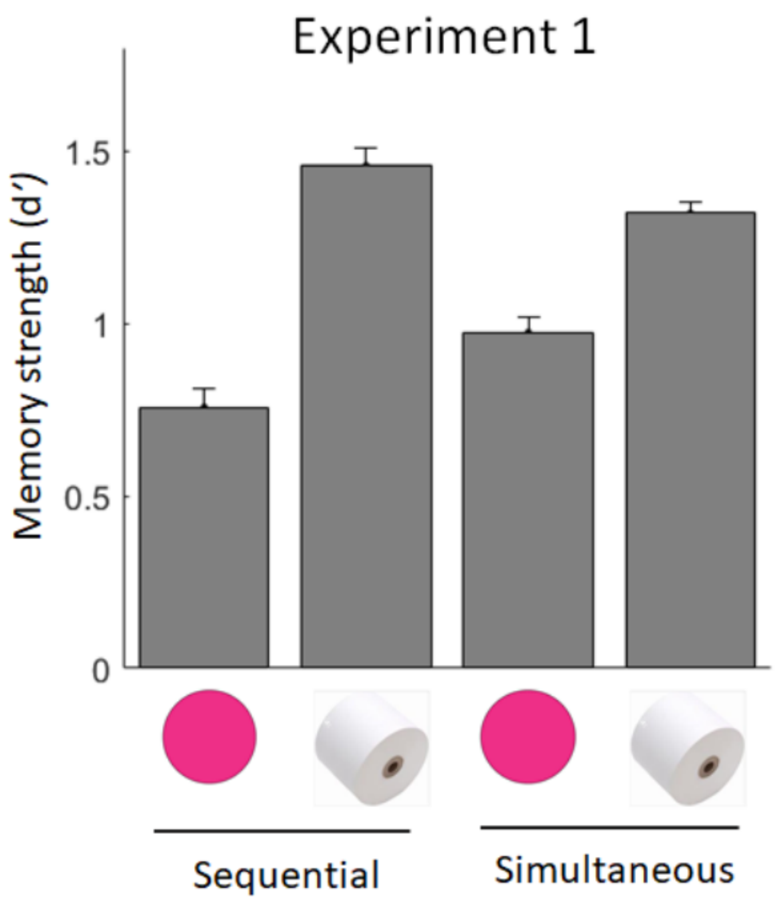


Ngiam et al. (2019) *JEP:G*

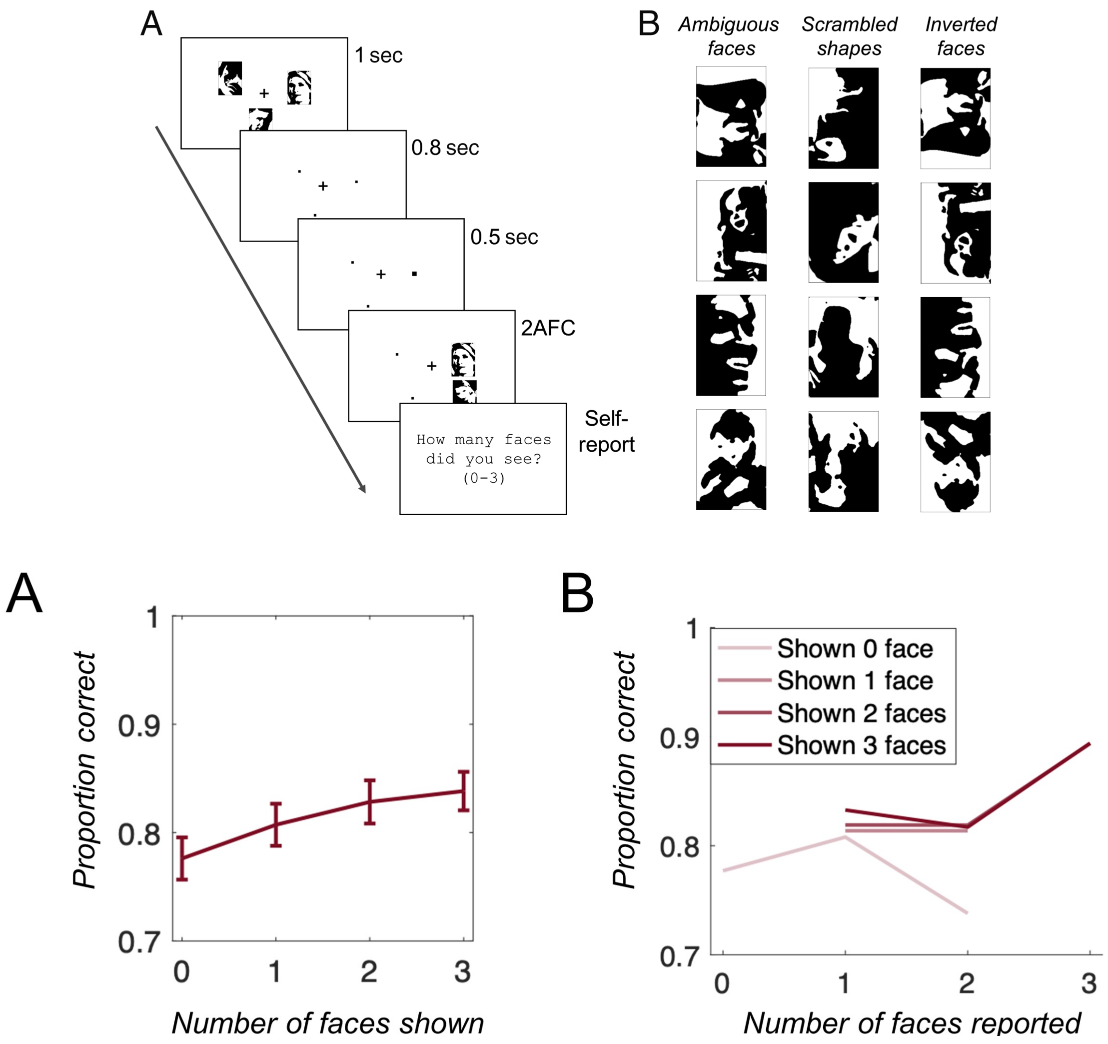


Xie and Zhang (2017) *M&C*

• Meaningfulness // real-world objects:

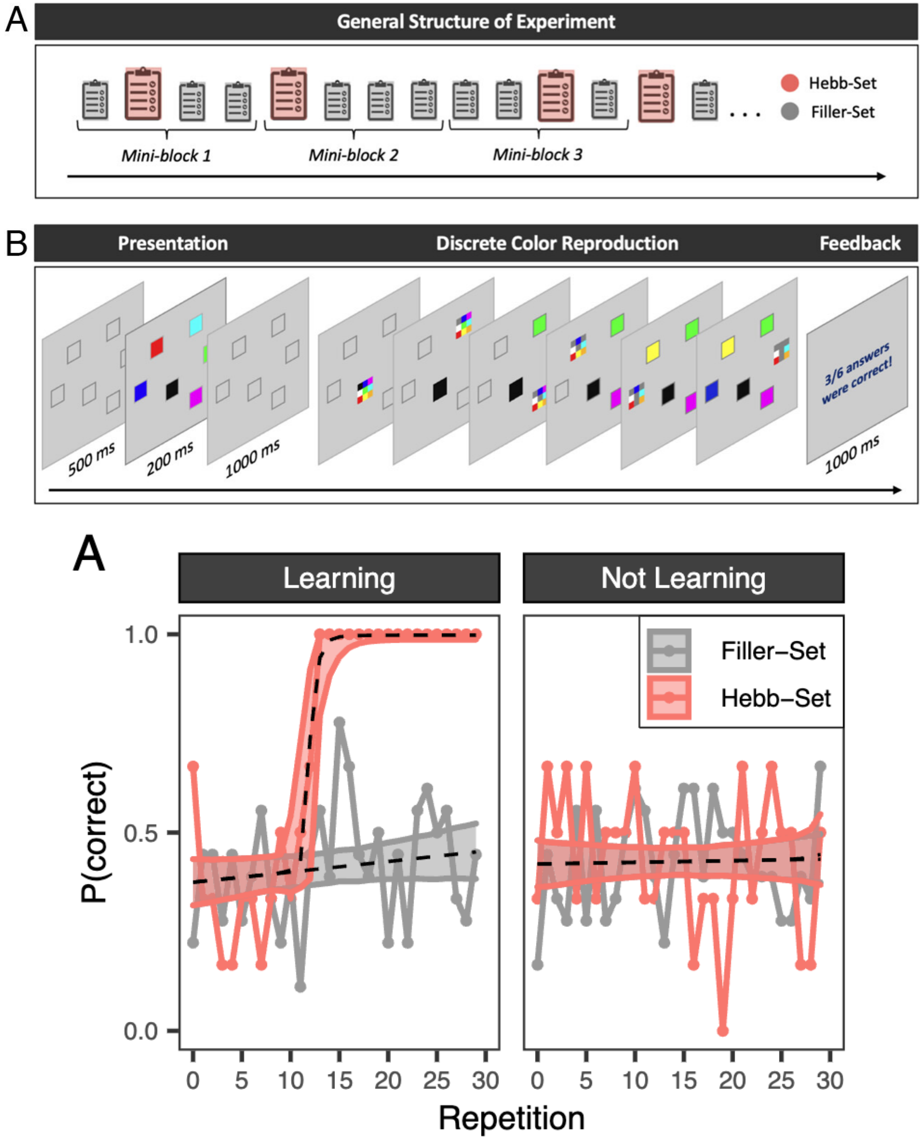


Brady and Störmer (2022) *JEP:LMC*

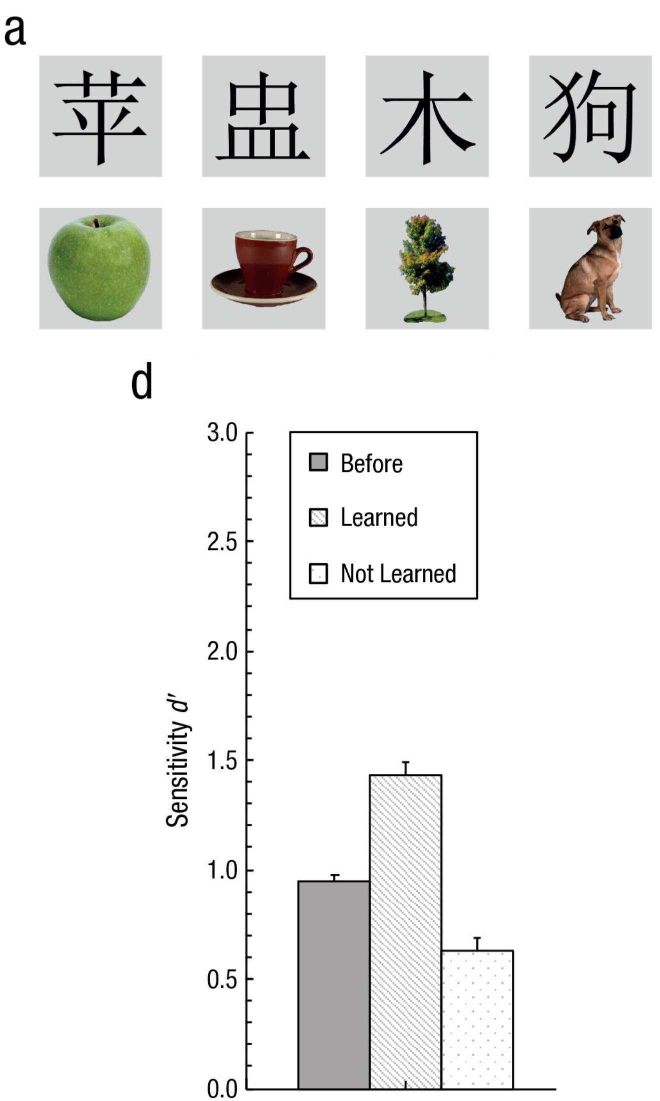


Asp et al. (2021) *JoCN*

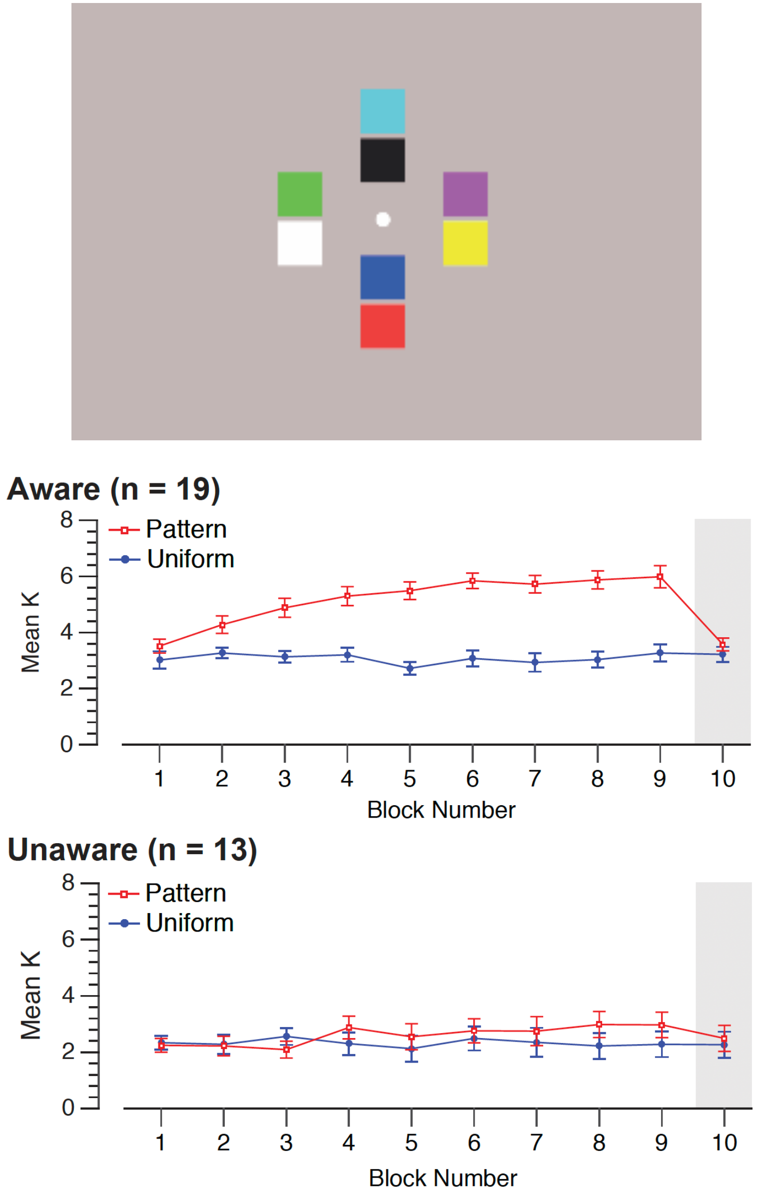
• Repetition learning // associative learning:



Musfeld et al. (2023) *PNAS*



Conci et al. (2023) *Psych Sci*



Ngiam et al. (2019) *JEP:G*

How is working memory performance improved?

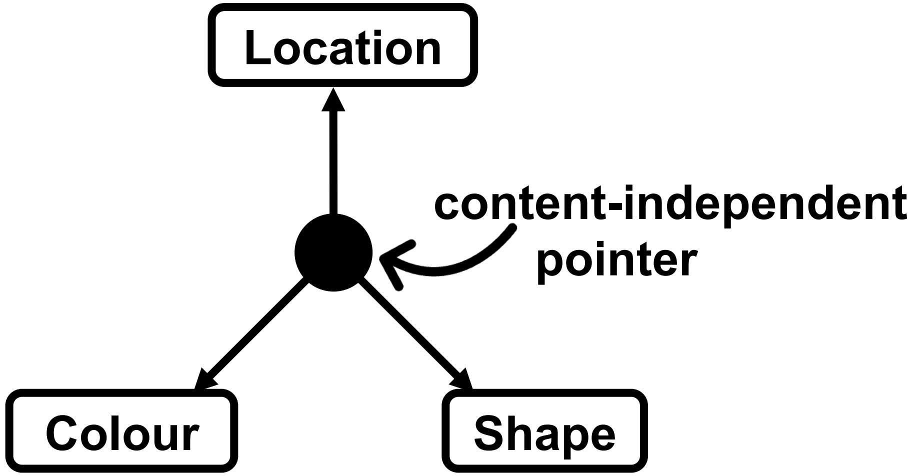
- Working memory load may be *expanded* for familiar // meaningful // learned stimuli
  - Additional resources are recruited allowing a greater amount of items to be held within working memory

- Working memory load is reduced via *chunking*
  - Load is reduced by requiring fewer “chunks” to be held in working memory
  - Recall is improved by relying on recruitment of long-term memory

Pointers in working memory

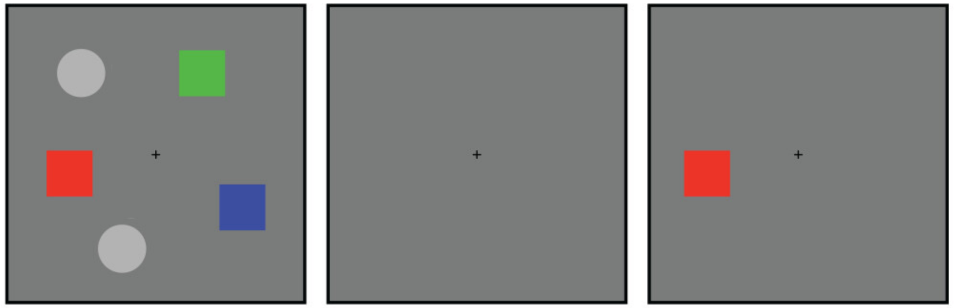
- Pylyshyn (2009) proposed the visual system has an indexing mechanism that keeps track of an individual object through its changes
  - This index is ***abstracted*** from the contents of the object

- We propose that items in working memory are assigned to a content-independent pointer

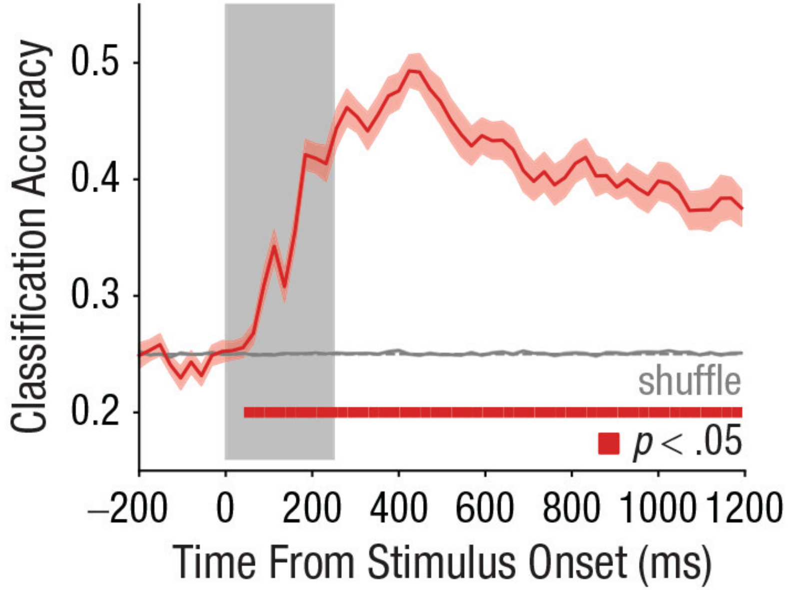


Multivariate neural signature of WM pointers

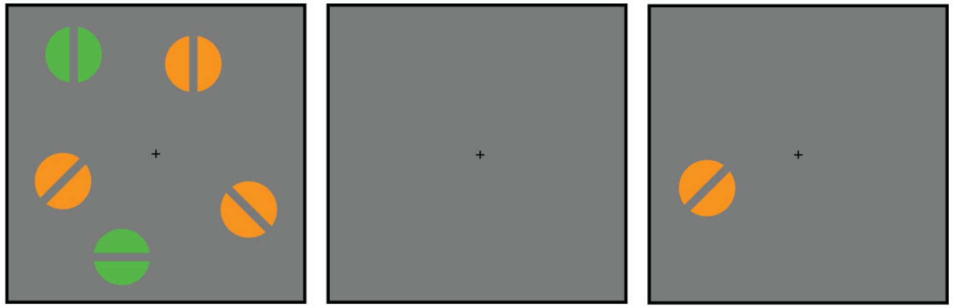
Experiment 1: Color



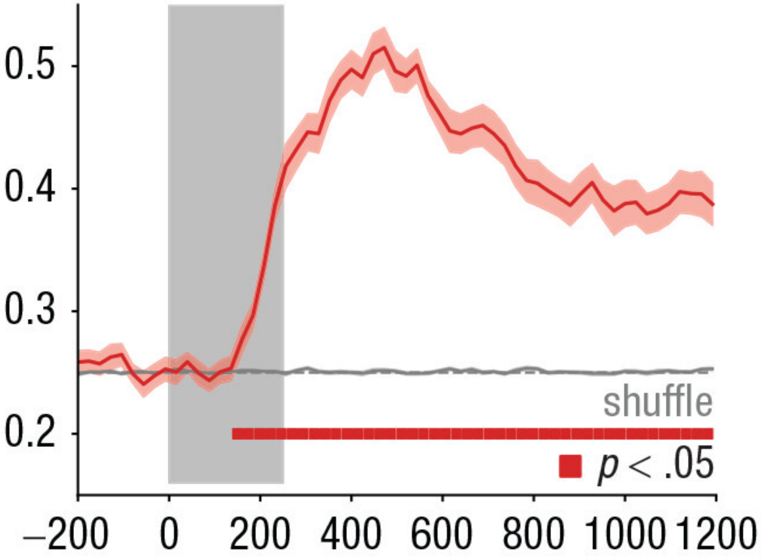
Train and test

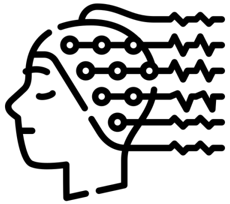


Experiment 2: Orientation



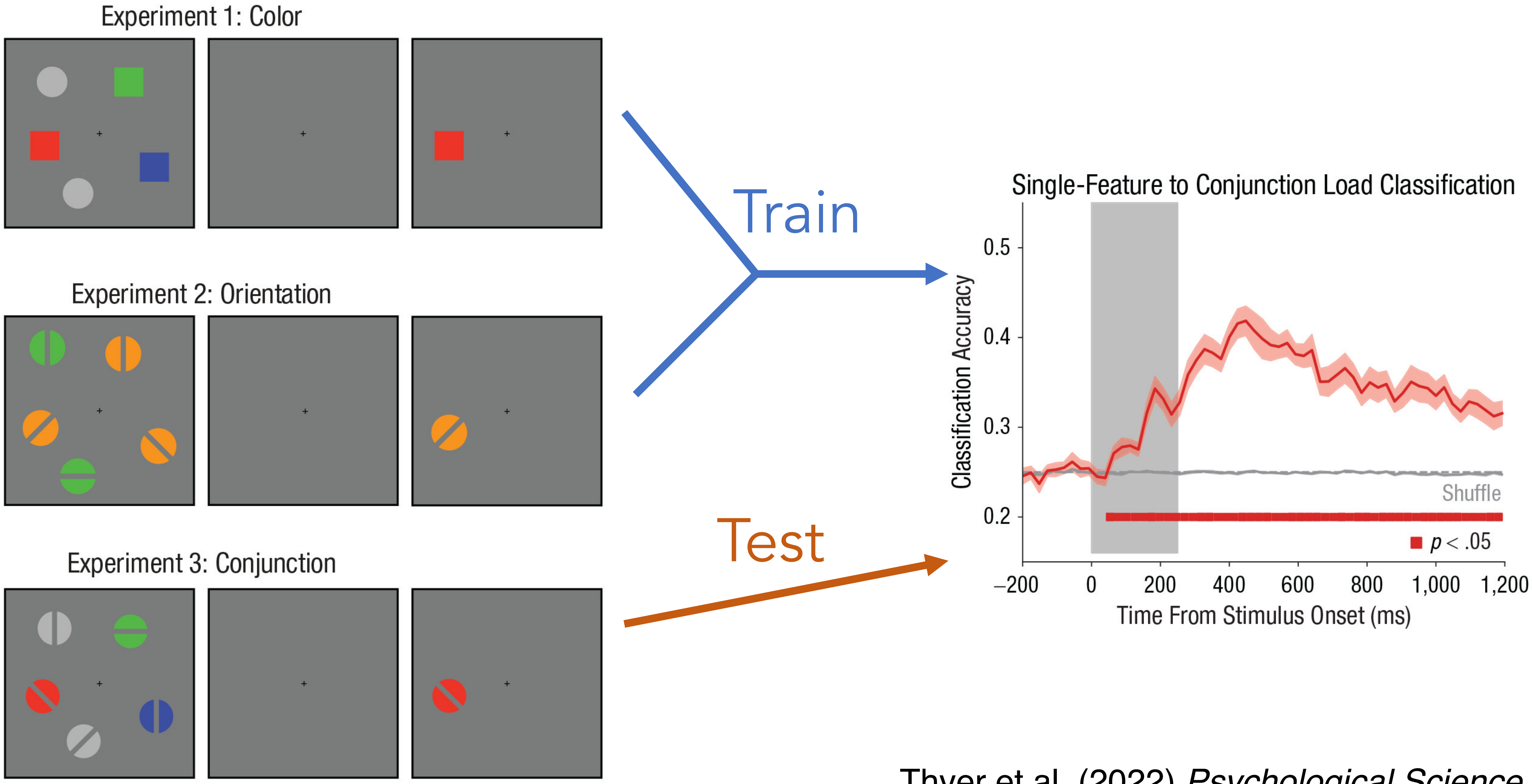
Train and test





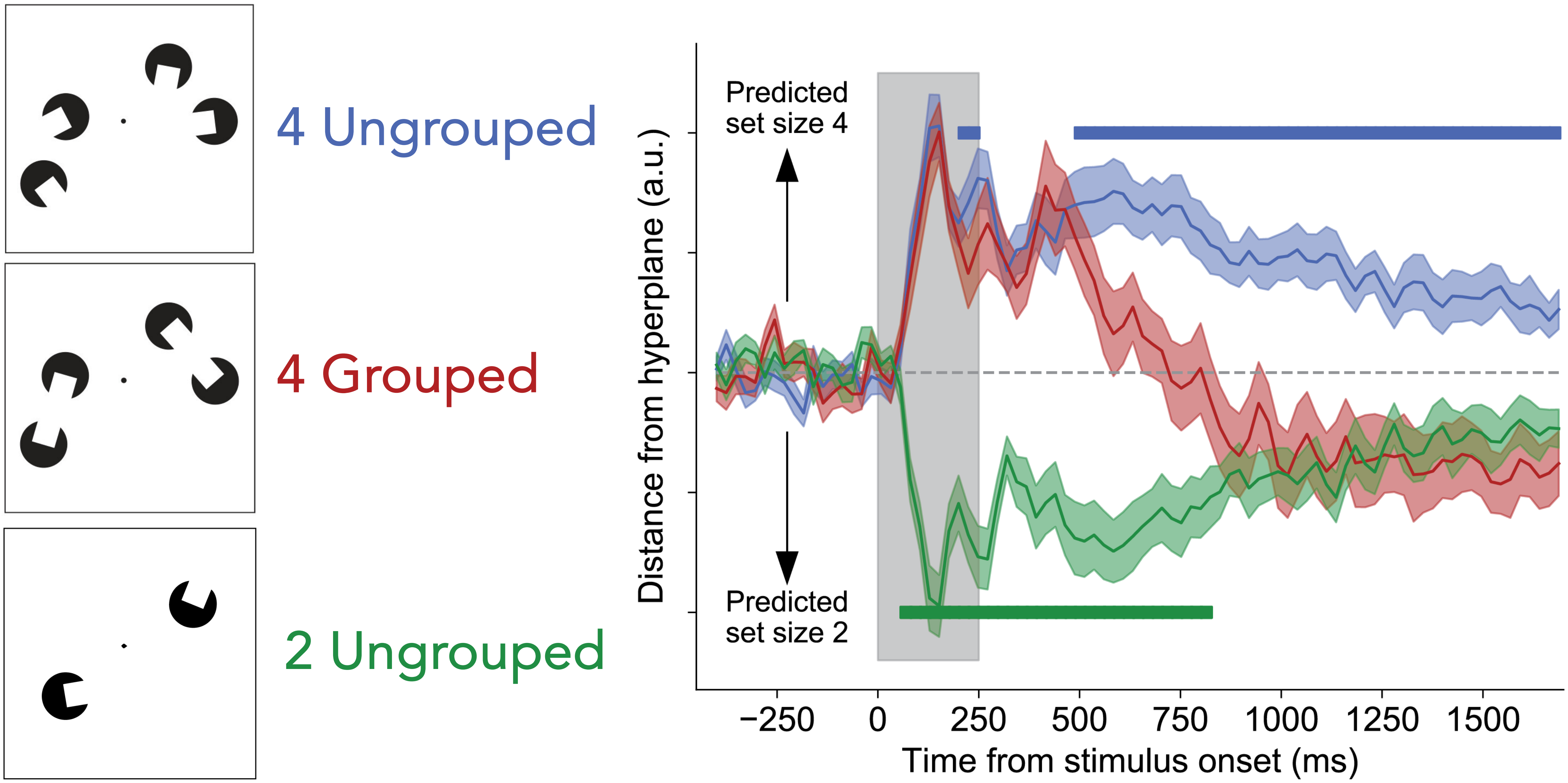
Thyer et al. (2022) *Psychological Science*

Multivariate neural signature of WM pointers



Thyer et al. (2022) *Psychological Science*

Multivariate neural signature of WM pointers



Thyer et al. (2022) *Psychological Science*

Multivariate neural signature of WM pointers

Henry Jones

- The multivariate load signal for pointers is dissociated from spatial attention
  Jones et al. (accepted), *Psychological Science*
- The load signal generalizes from color to motion coherence of random dot kinematograms
  Henry's VSS talk this year

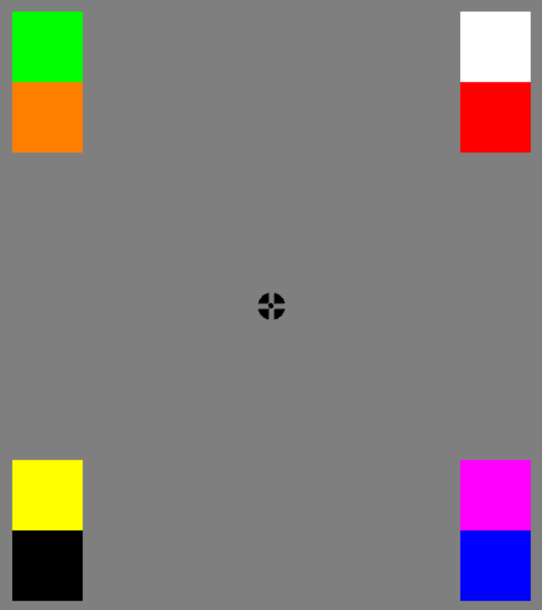
Darius Suplica

- The multivariate load signal is shared for audio and visual stimuli
  in prep

Do working memory pointers connect to long-term memory?

Experiment 1: Training

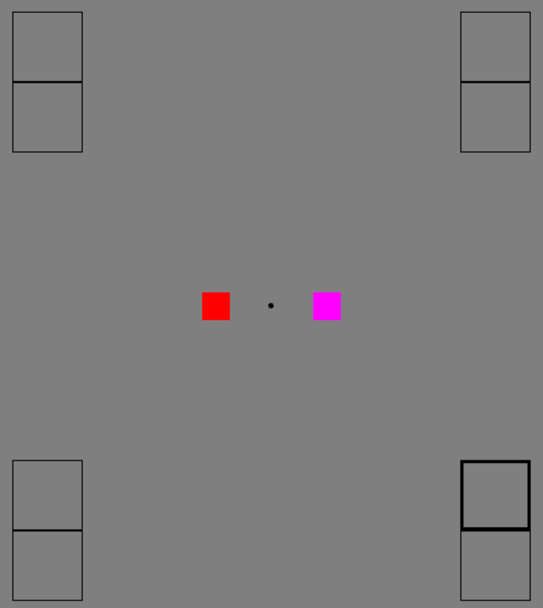
- Subjects completed 600 trials to learn four color pairs:



Experiment 1: Training

Experiment 1: Training

- Two alternative-forced choice – which color was in the bolded location?



Experiment 1: Pre-training and post-training

- Before training – 4 random colors
- After training – 4 paired colors (two learned pairs)

Experiment 1: Pre-training and post-training

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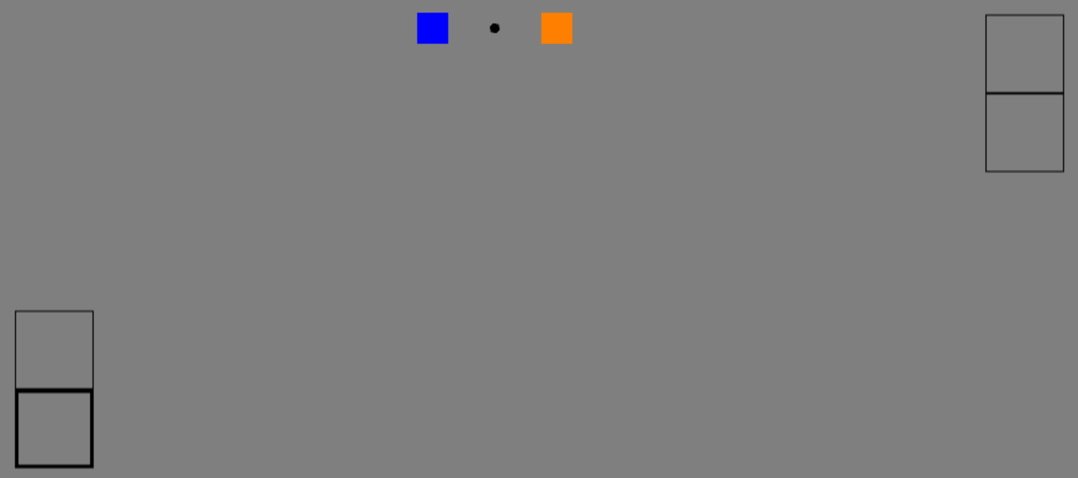
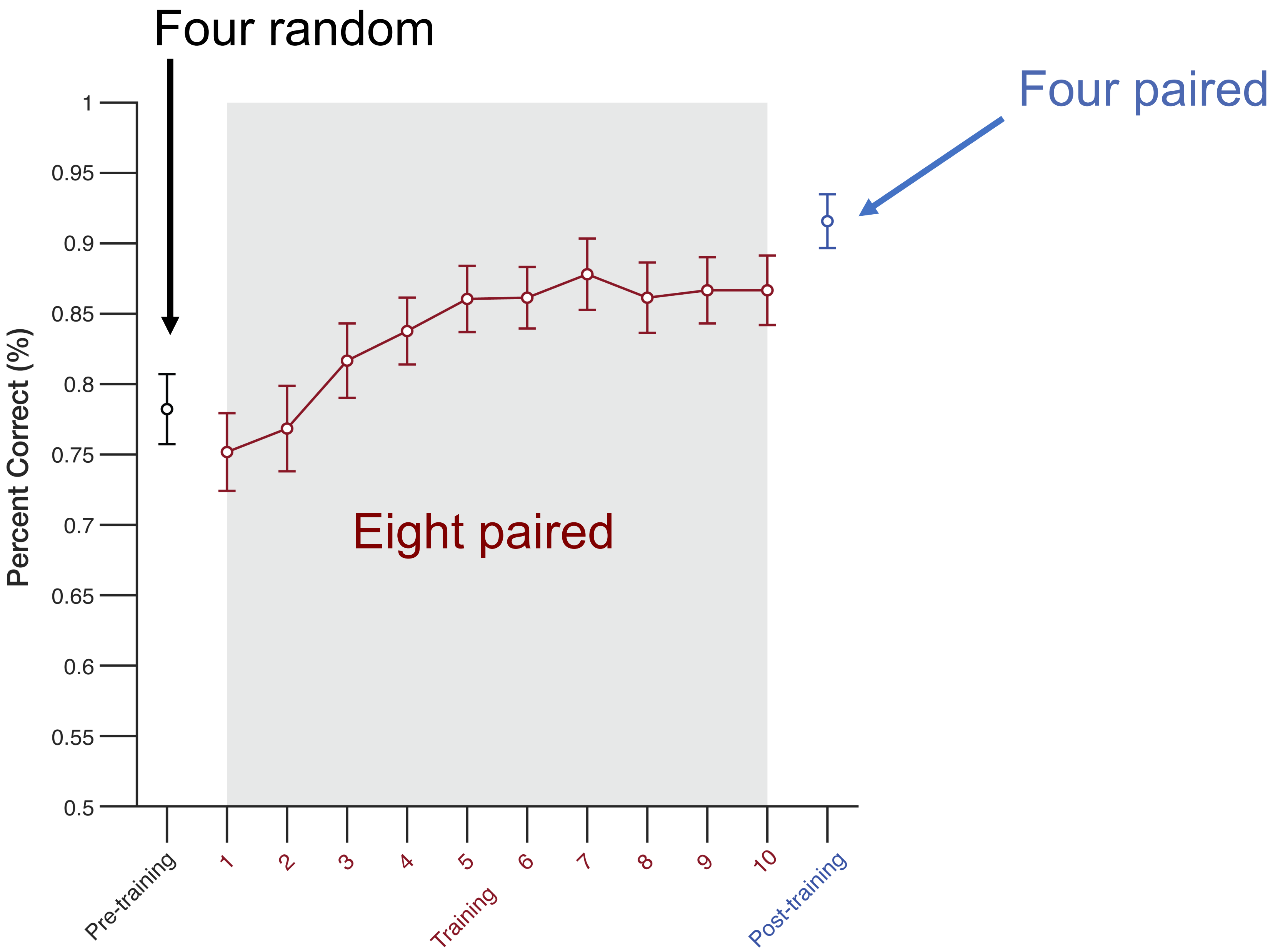
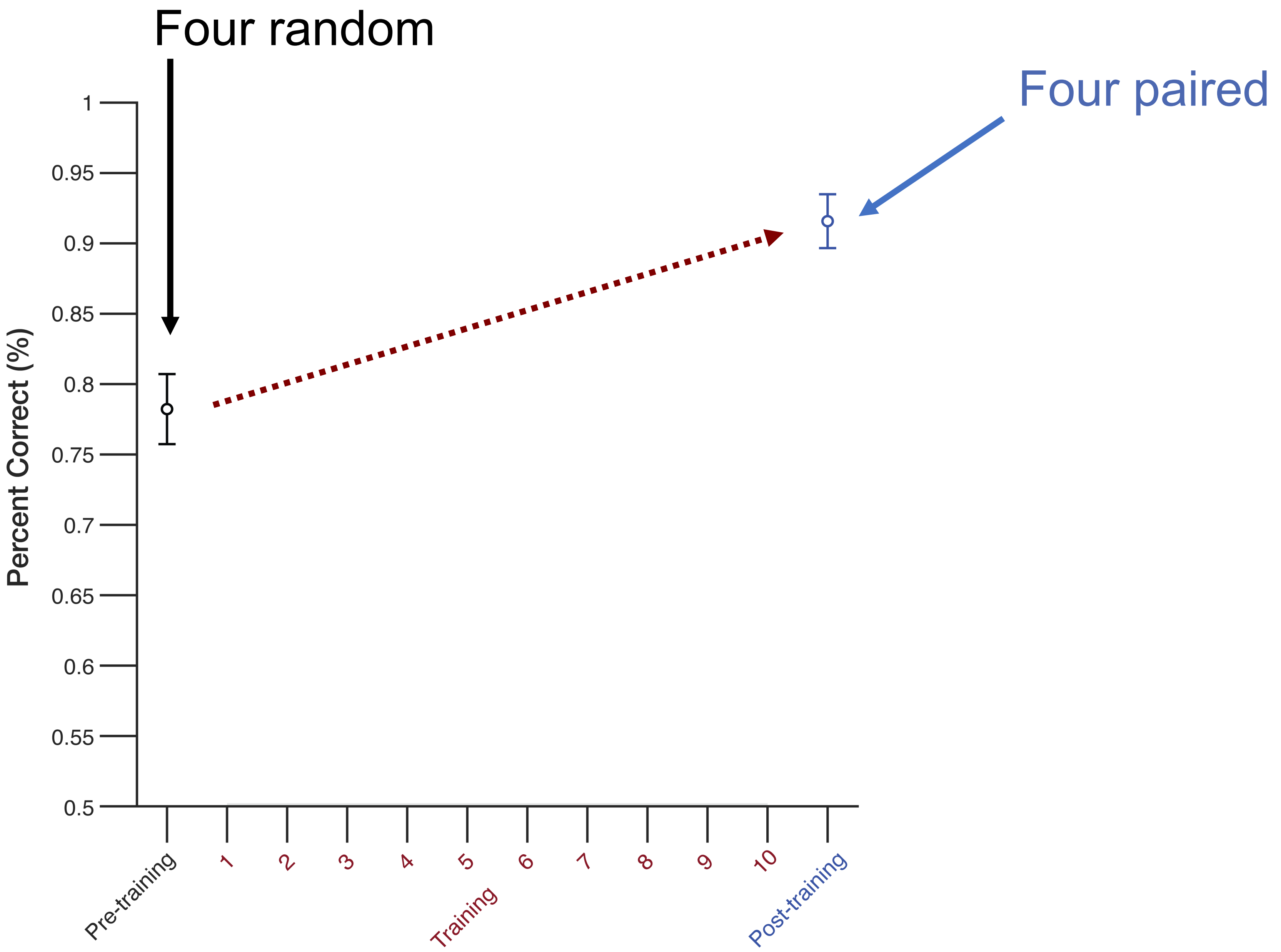


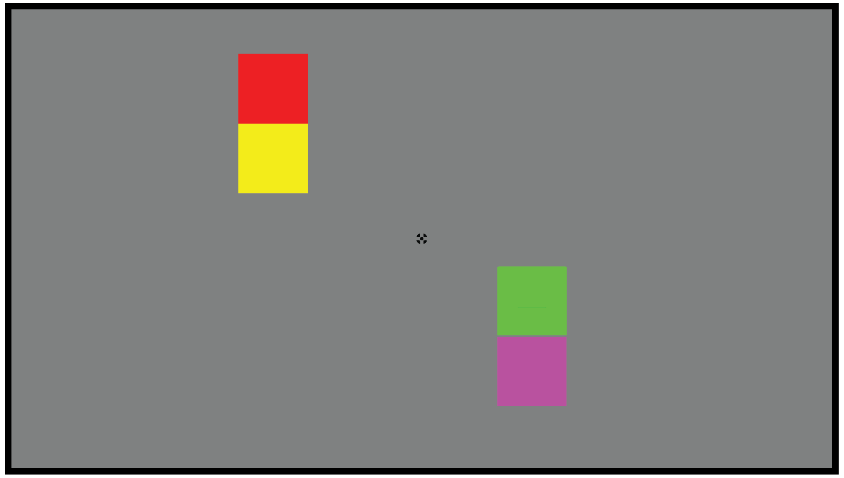
E1: training session – average performance



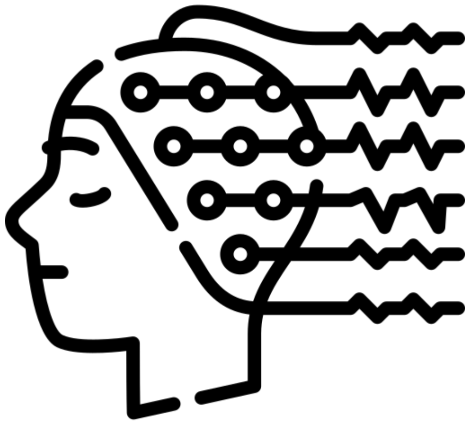
E1: training session – average performance

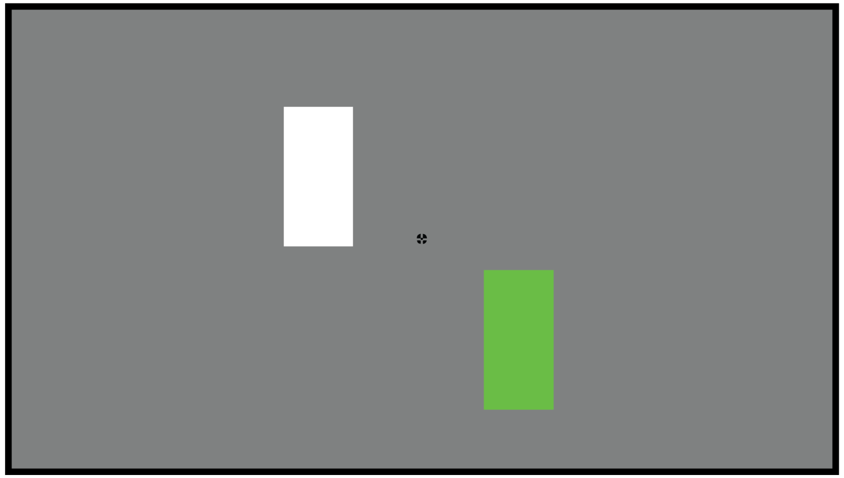


Experiment 1: EEG session



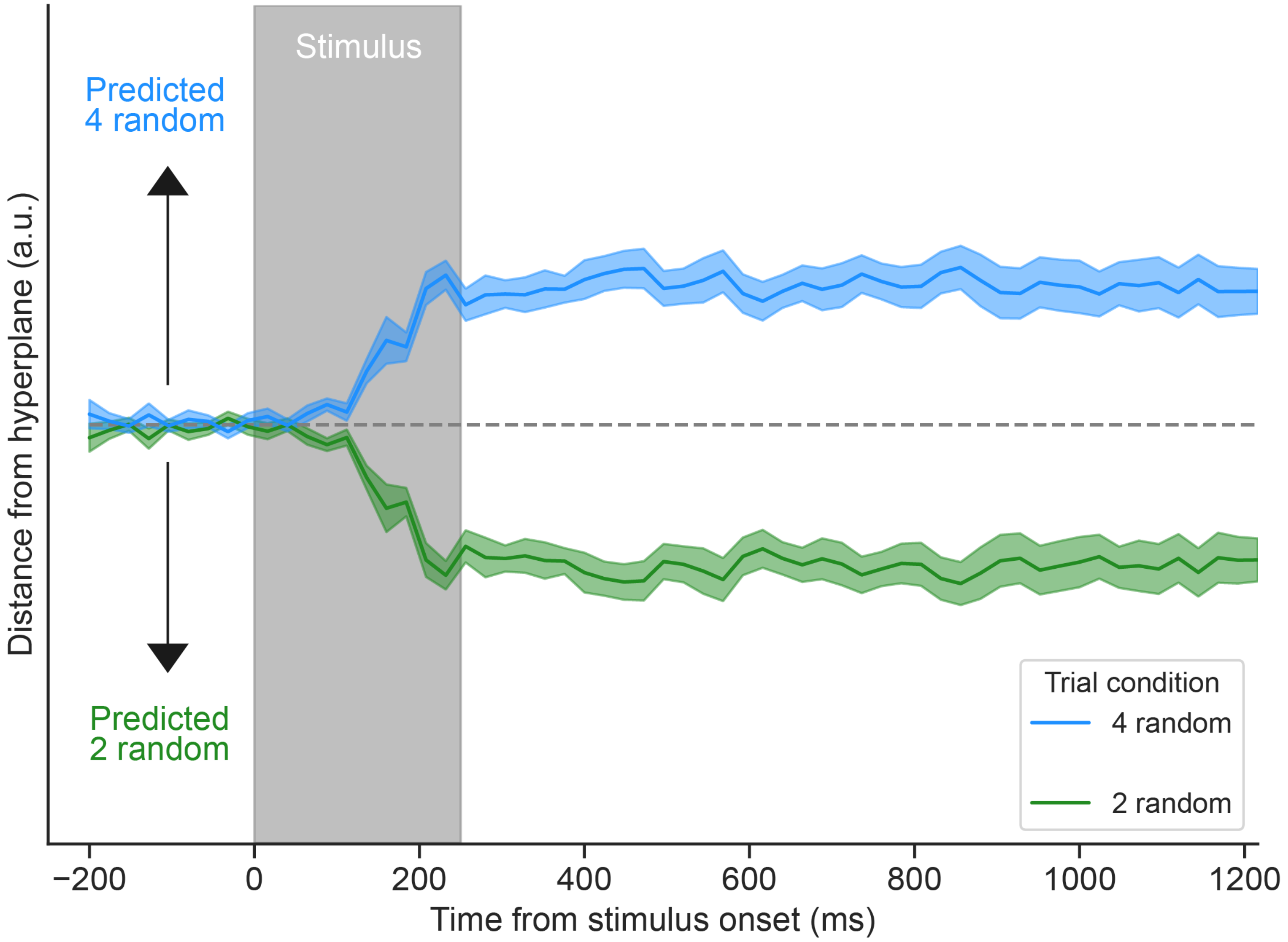
Four random
Four paired



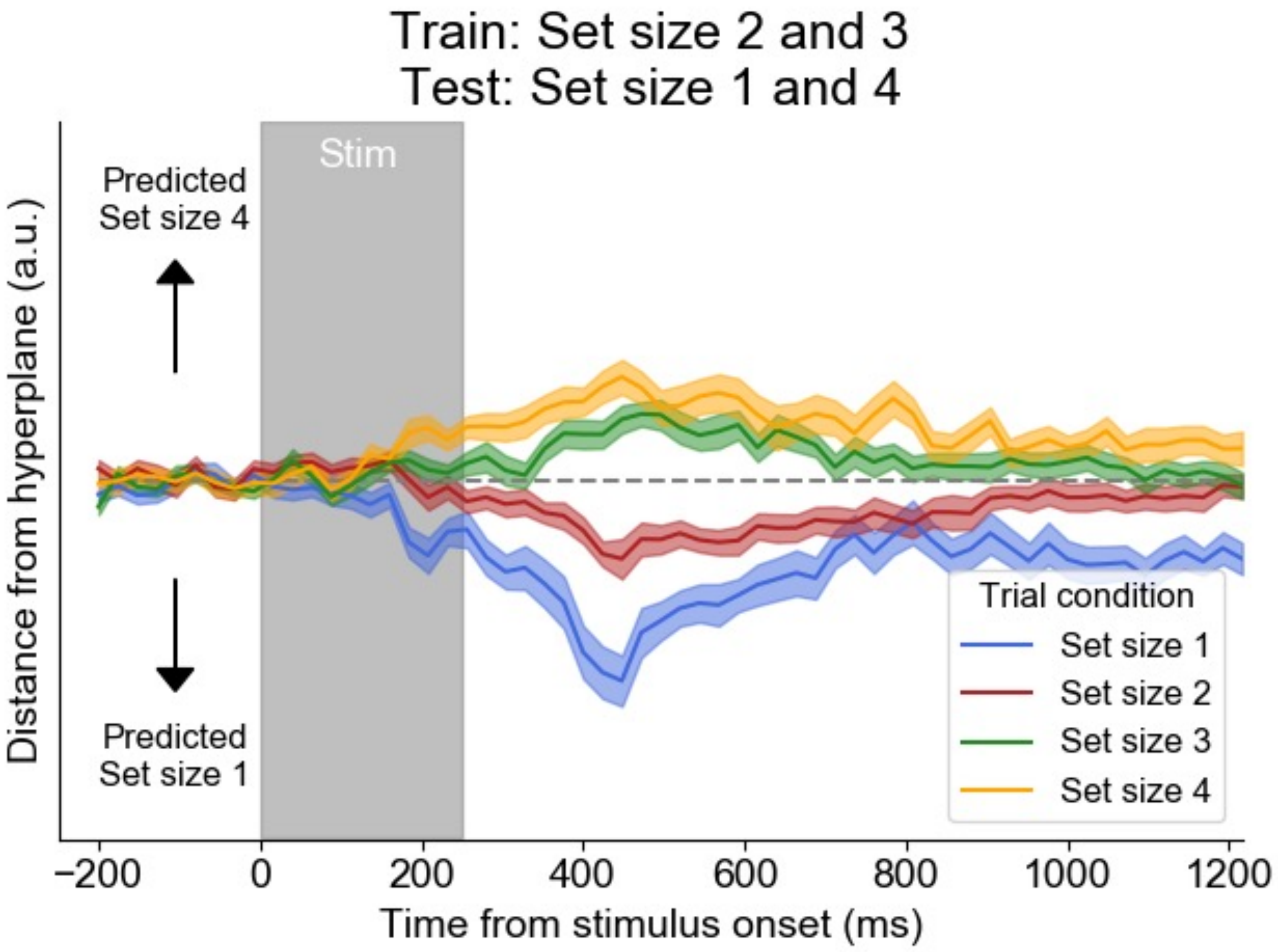


Two random

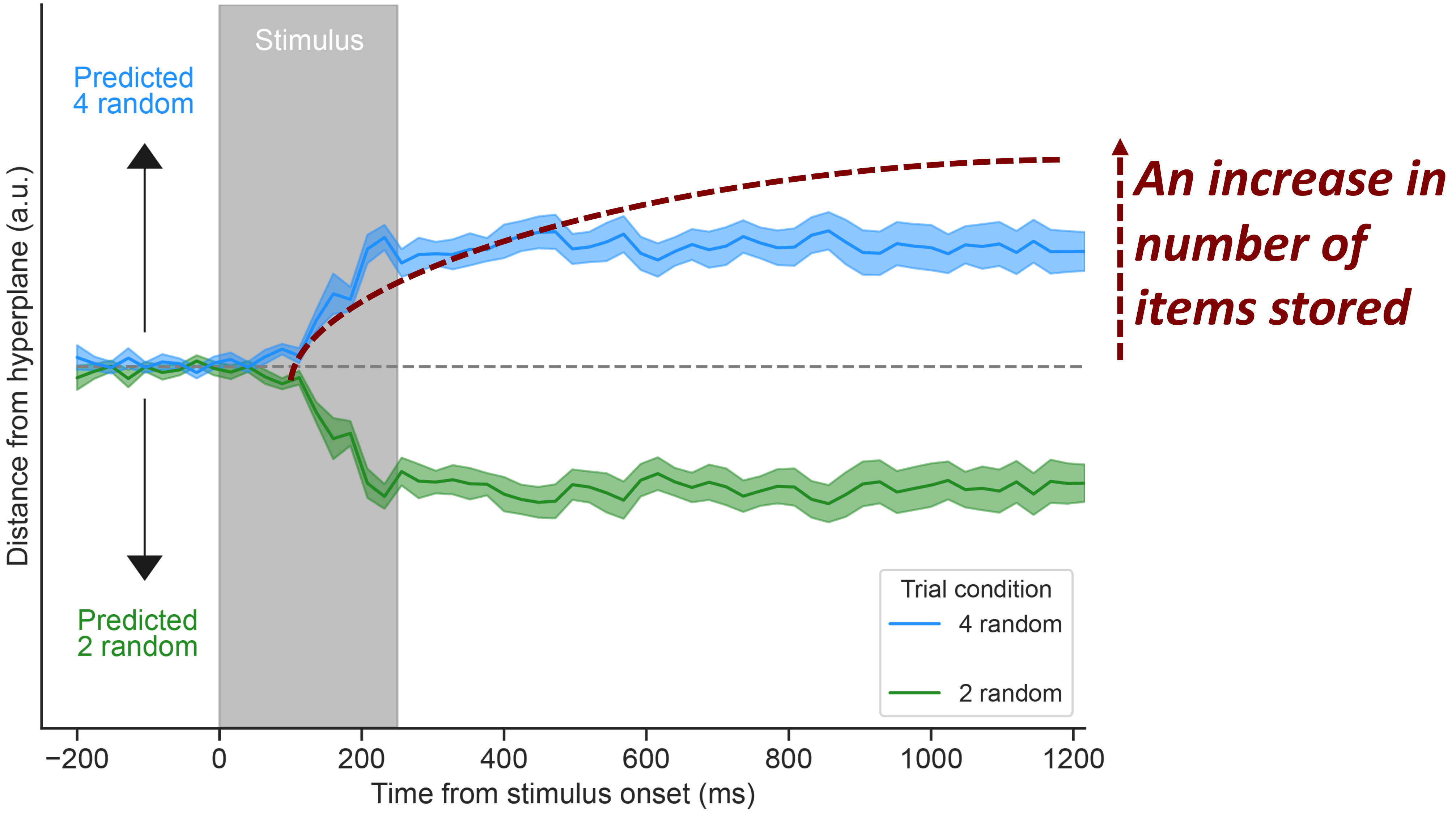
Train 2 random versus 4 random



Different loads on the hyperplane



Train 2 random versus 4 random, where is 4 paired?



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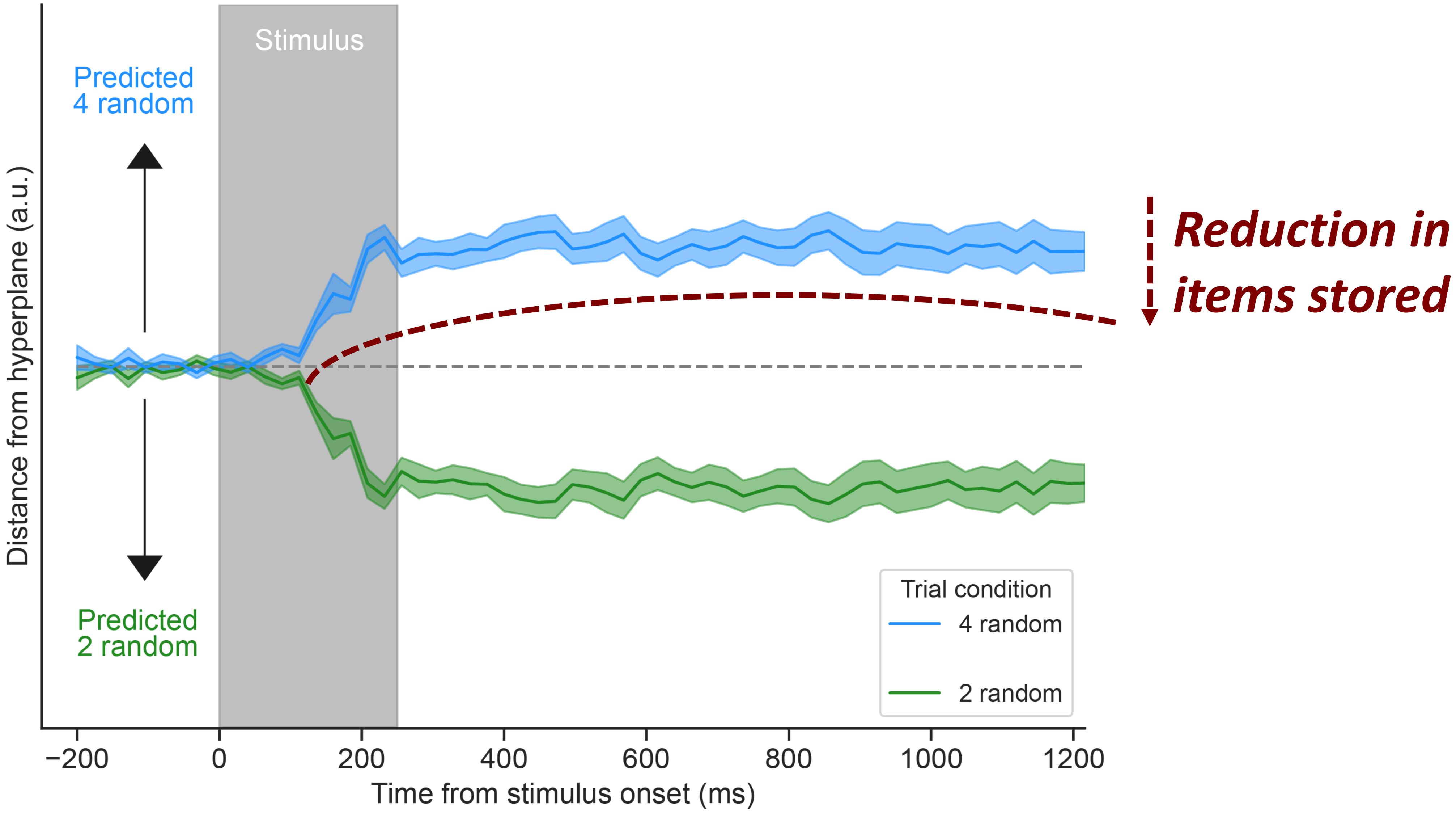
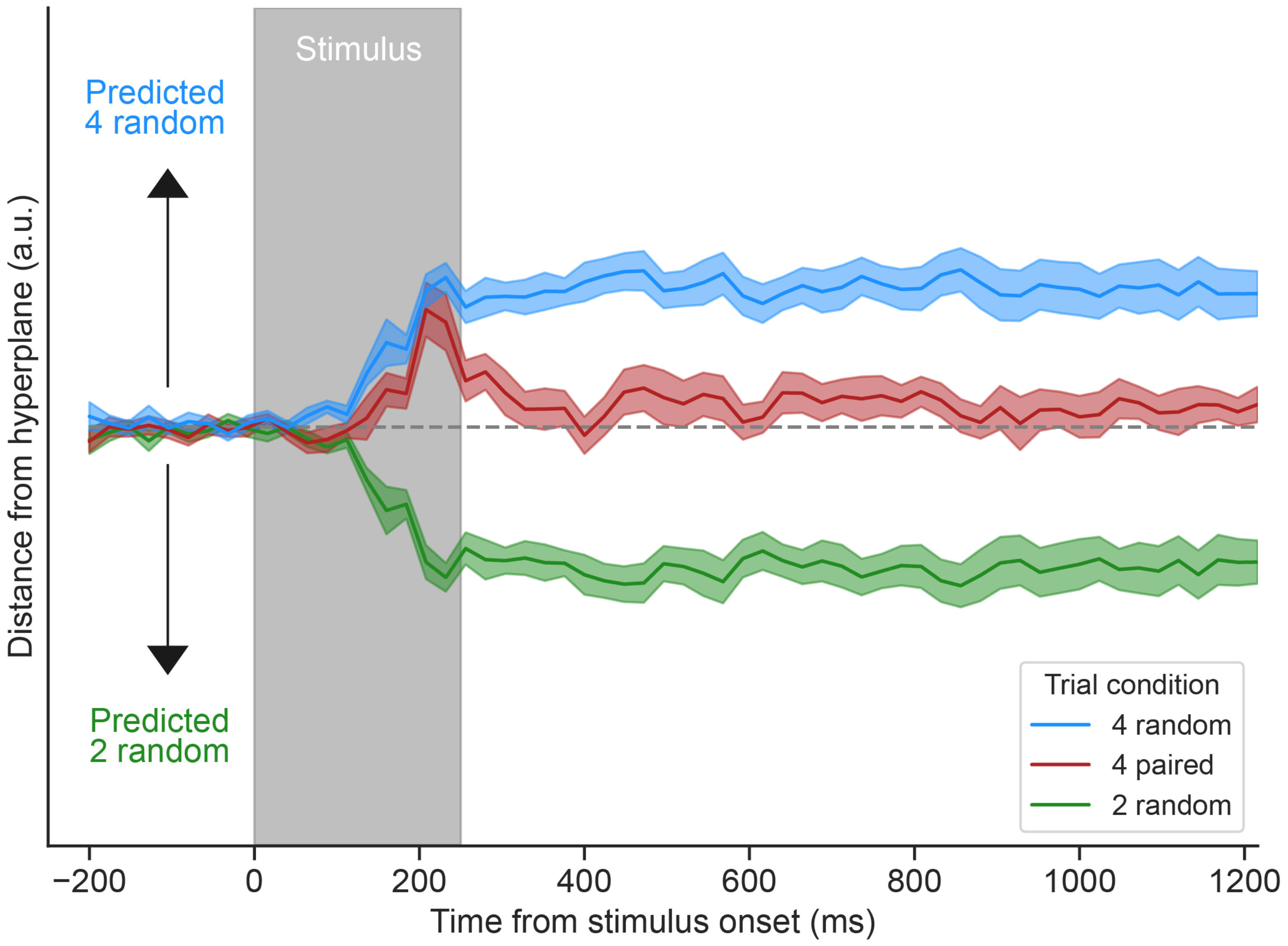
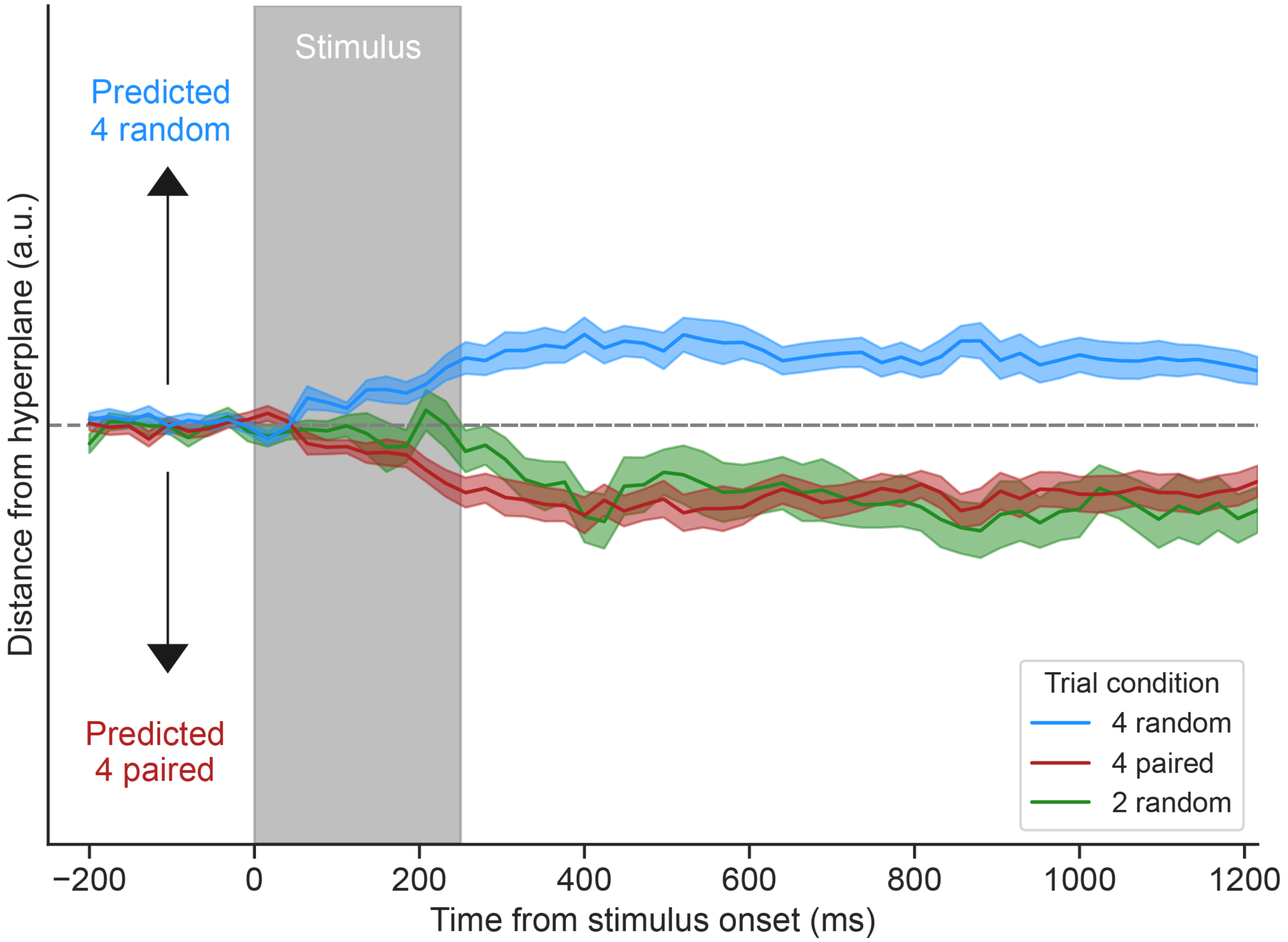


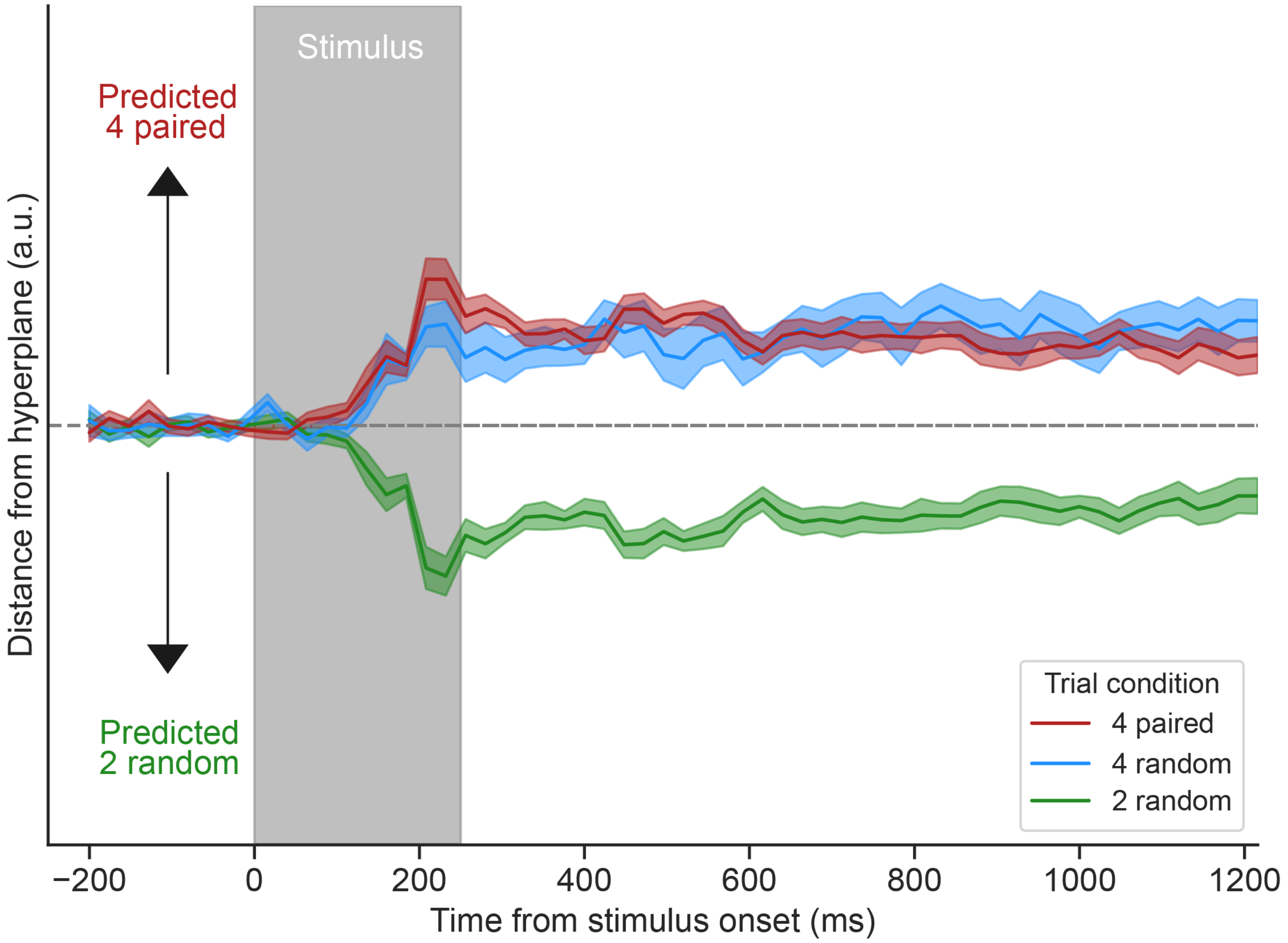
Train 2 random versus 4 random, test 4 paired



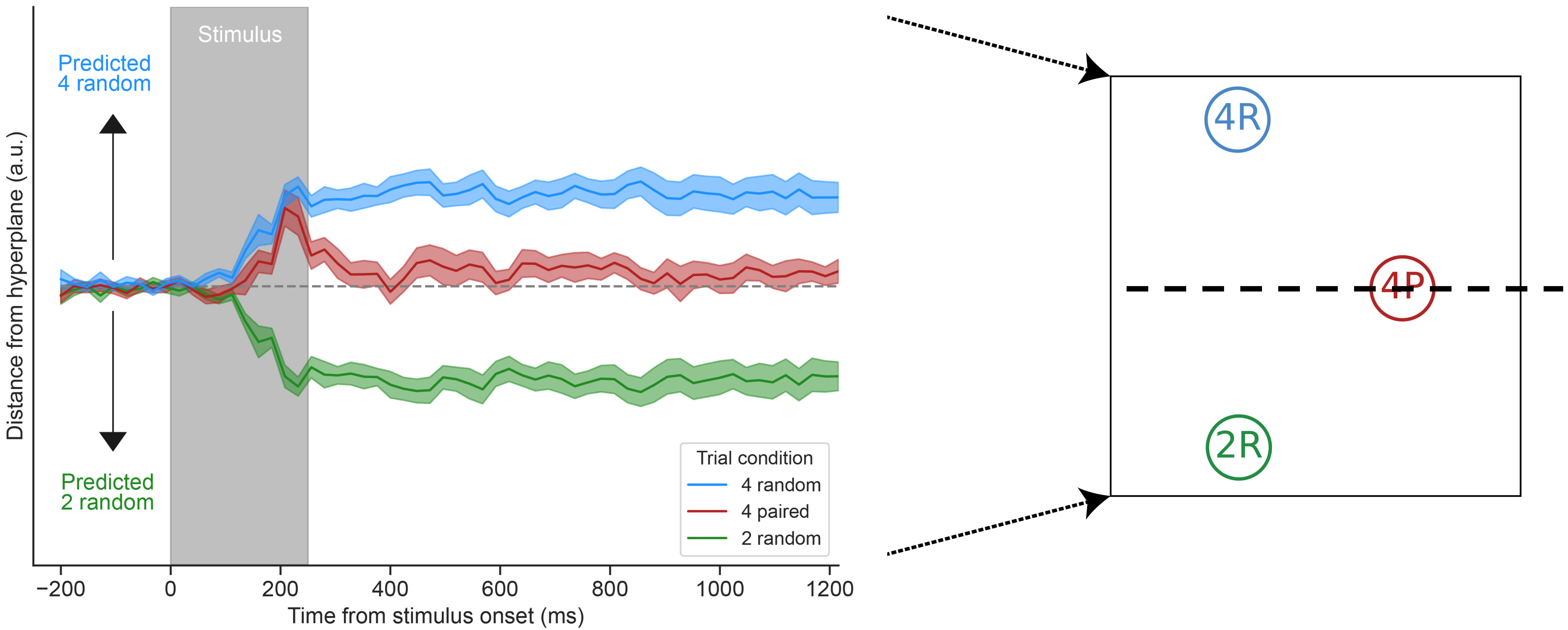
Train 4 random versus 4 paired, test 2 random



Train 2 random versus 4 paired, test 4 random



Multidimensional scaling



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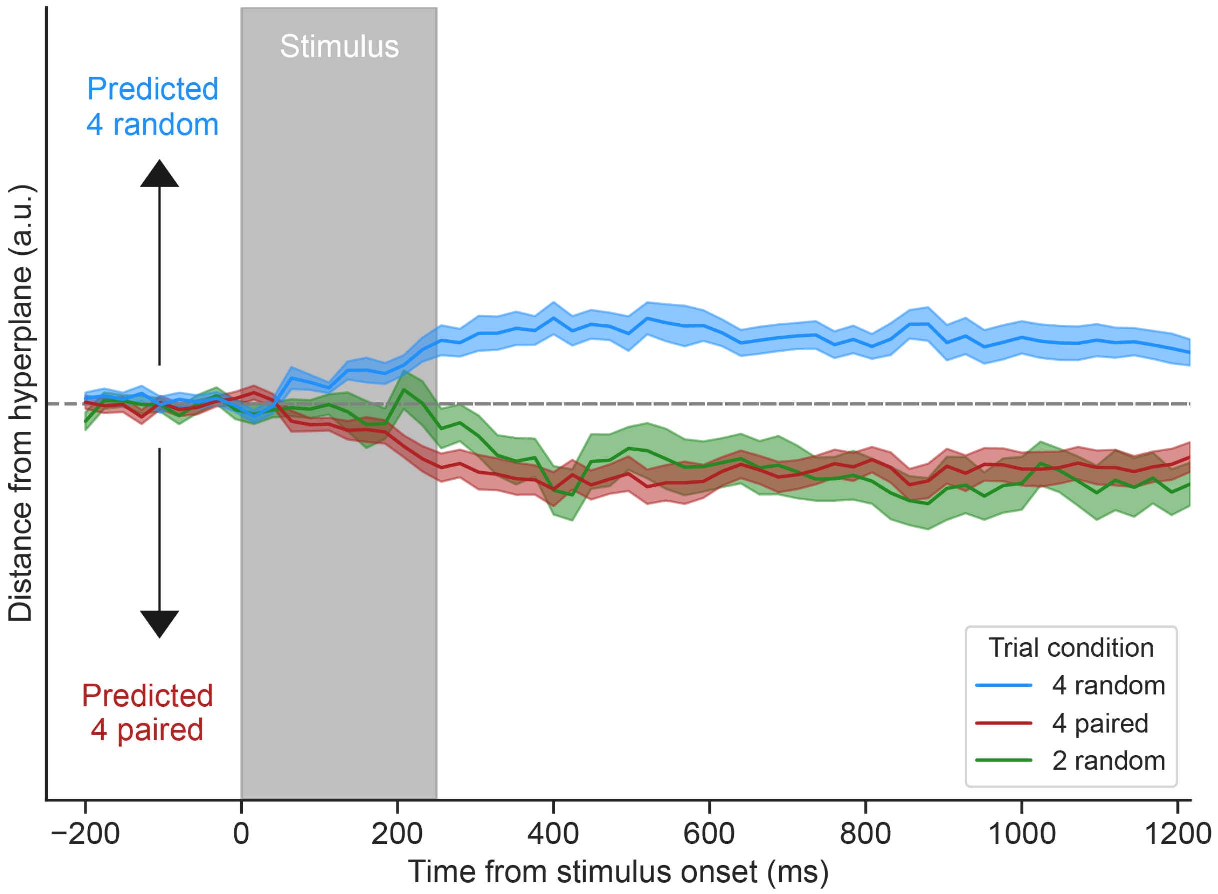

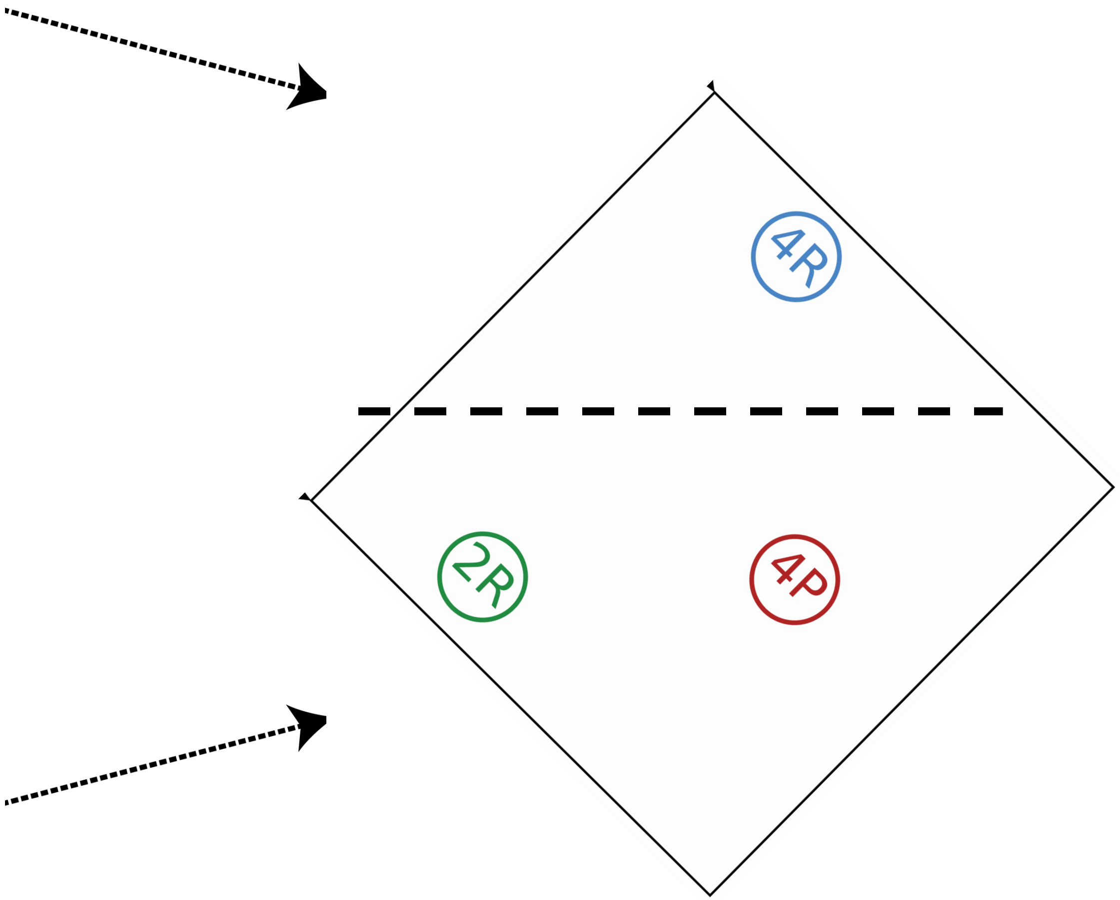

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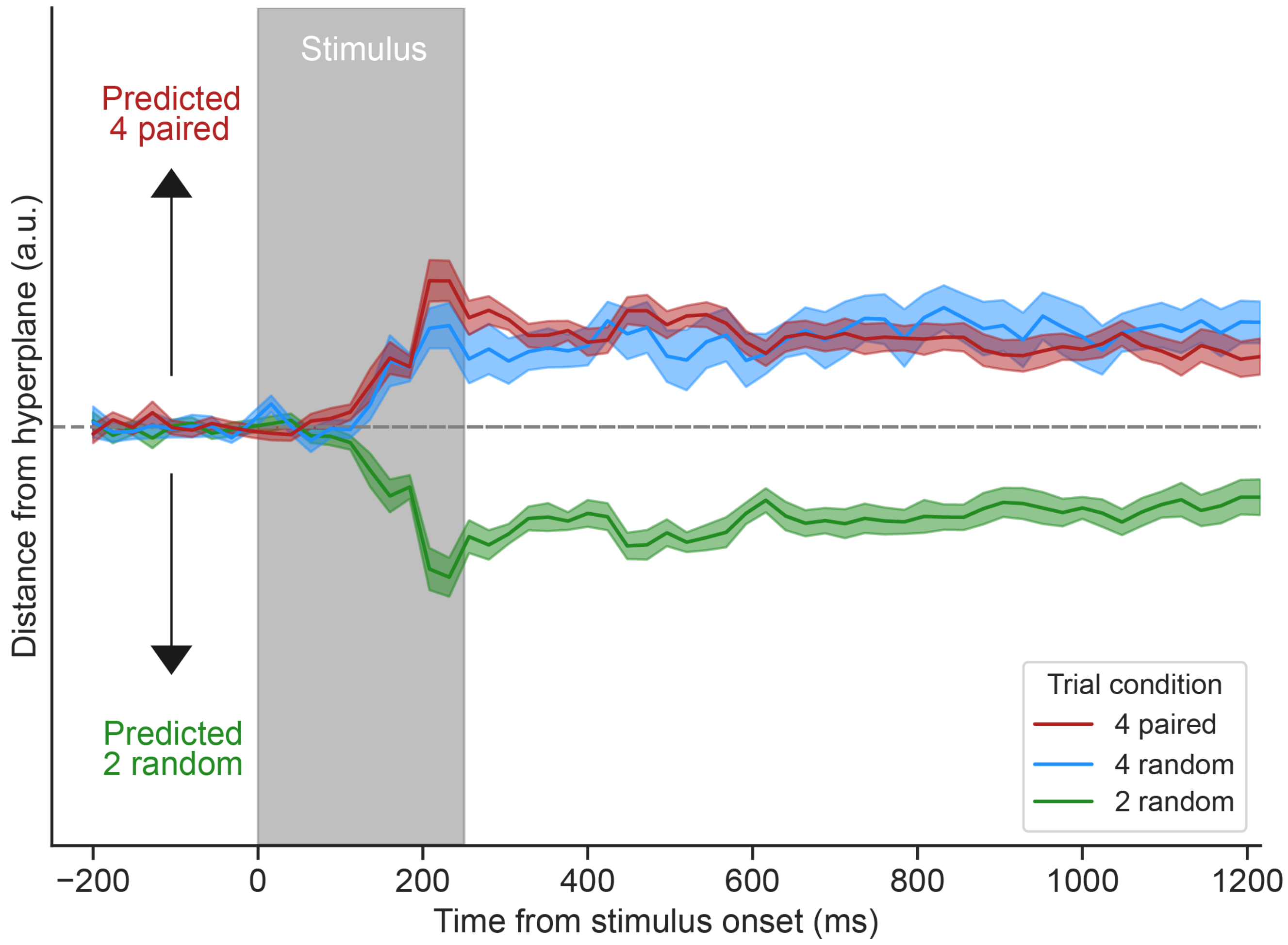
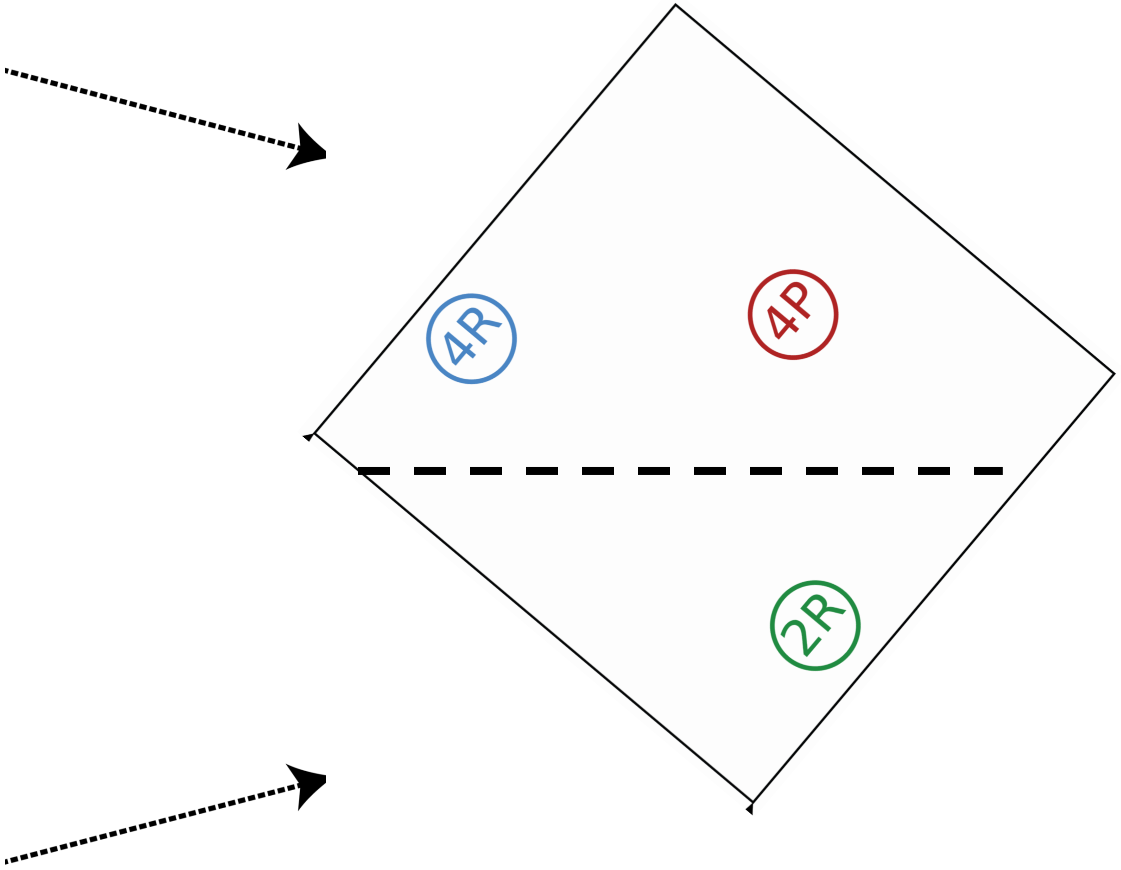
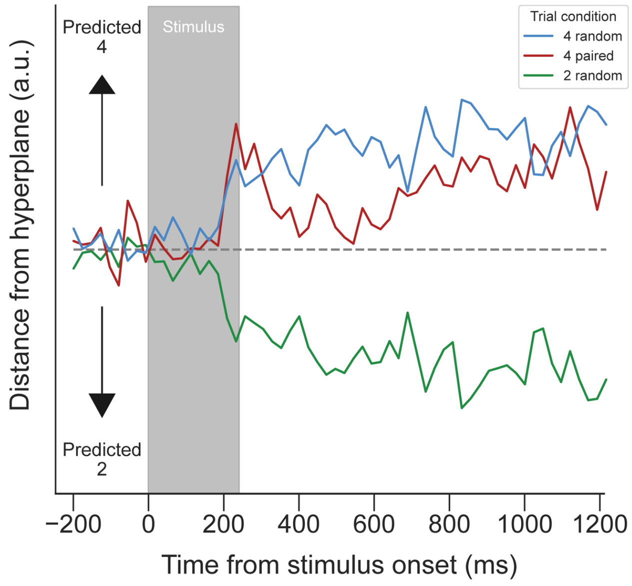
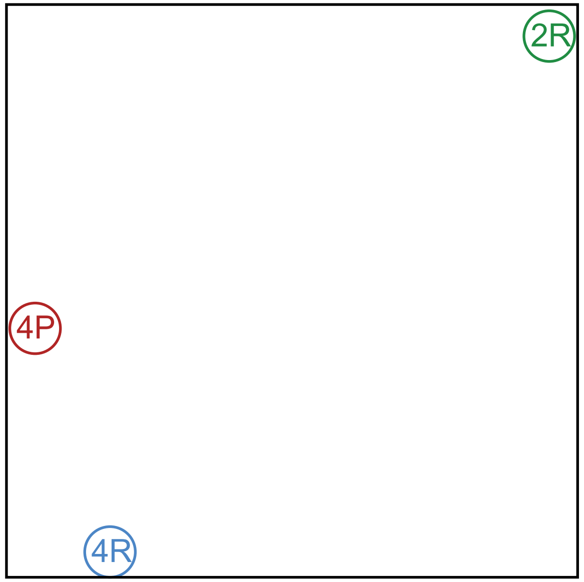




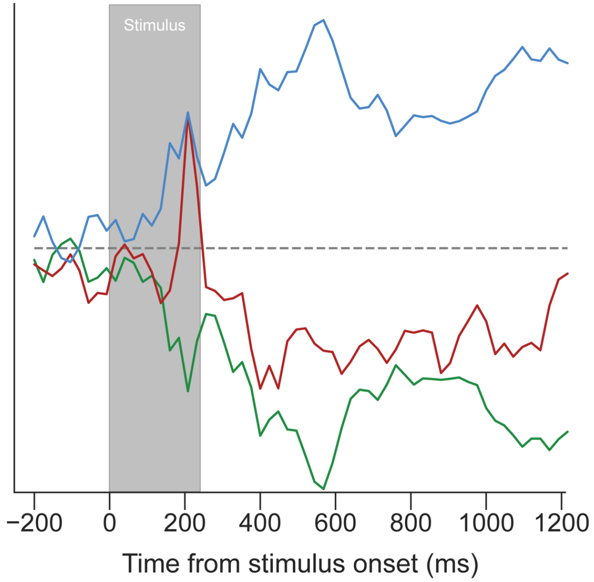
Individual differences

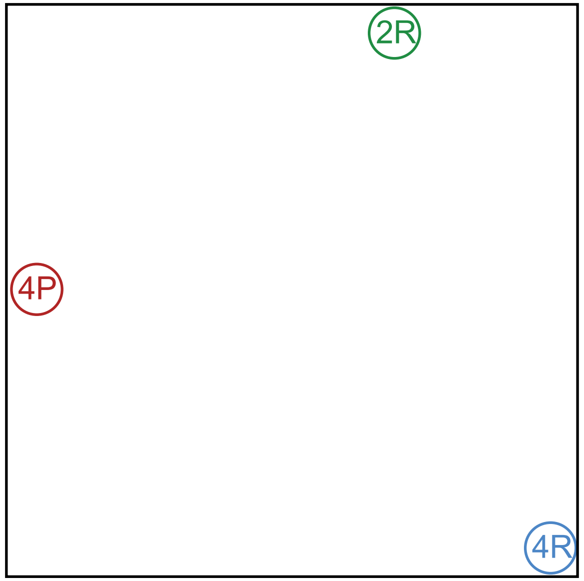
“Weak chunking”





“Strong chunking”





Individual differences

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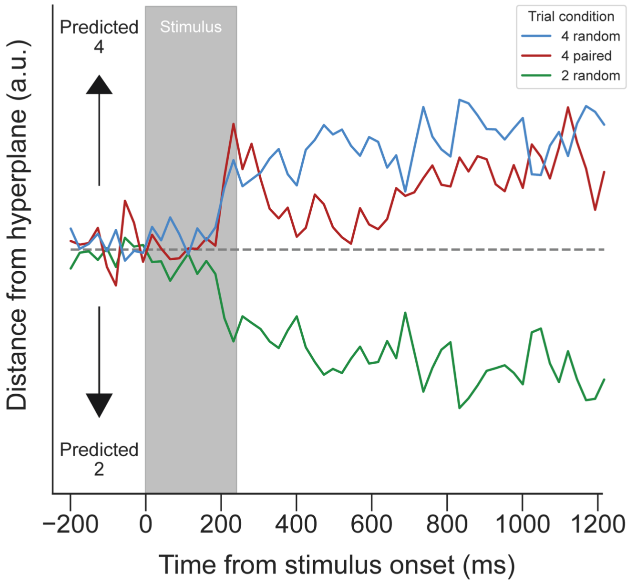
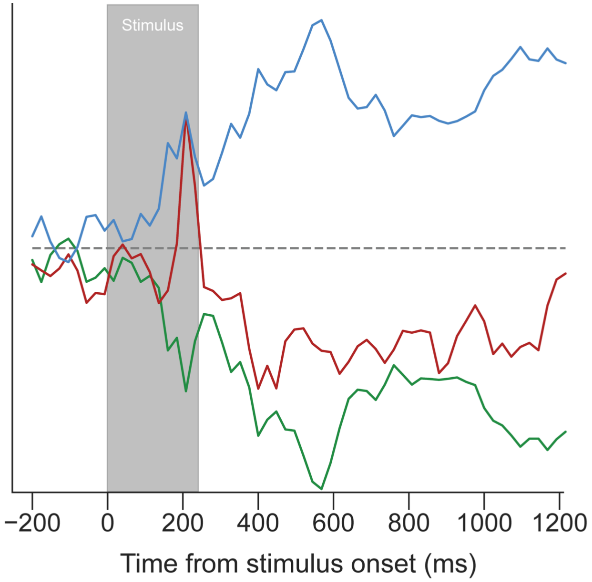
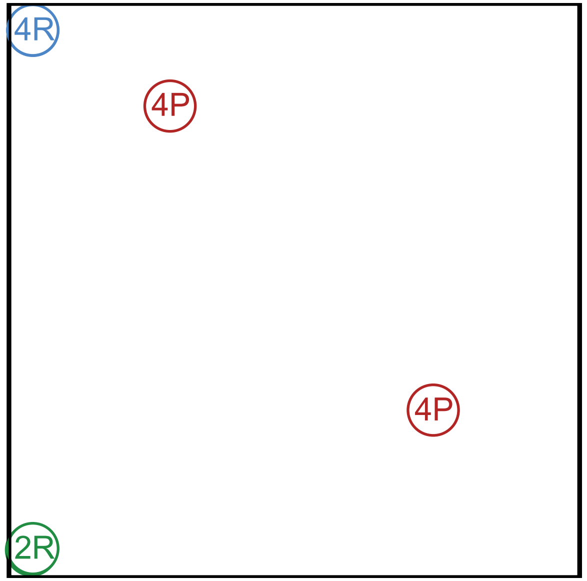
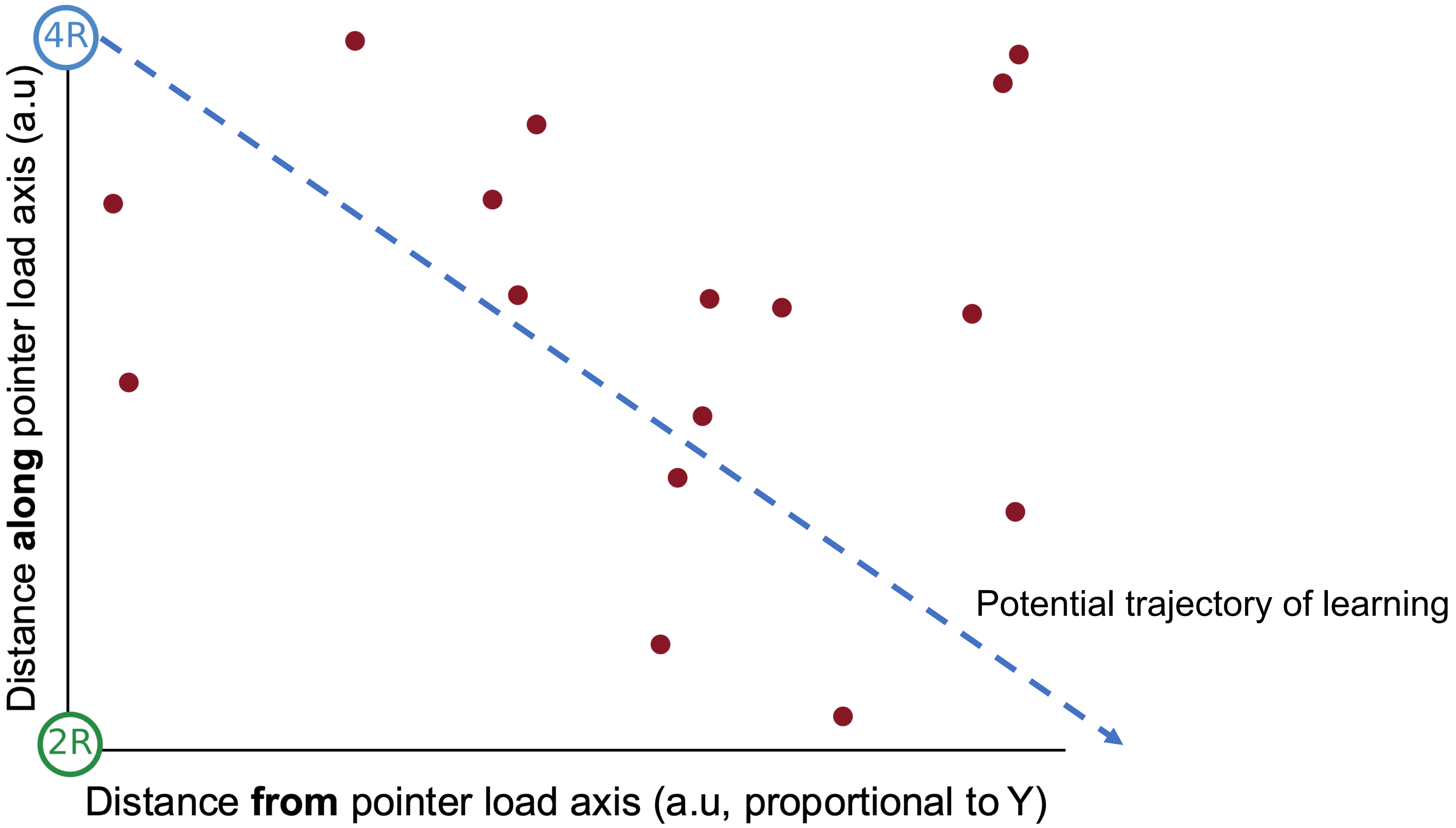


"Strong chunking"



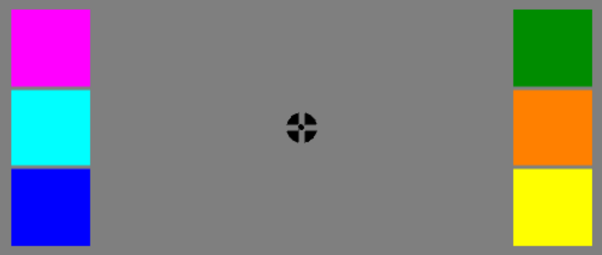


Individual differences



Experiment 2

- Trained subjects to learn three color triplets



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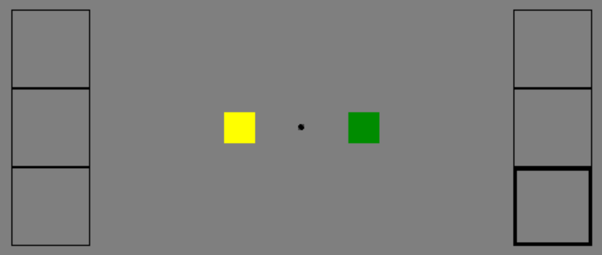
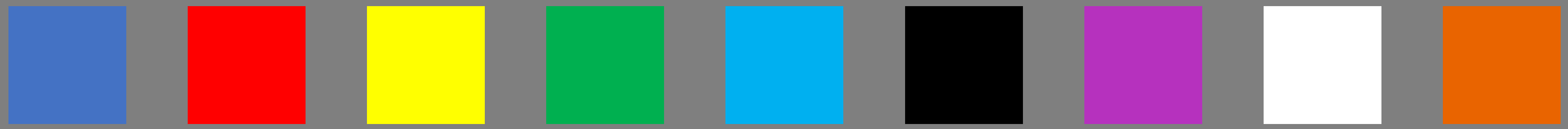


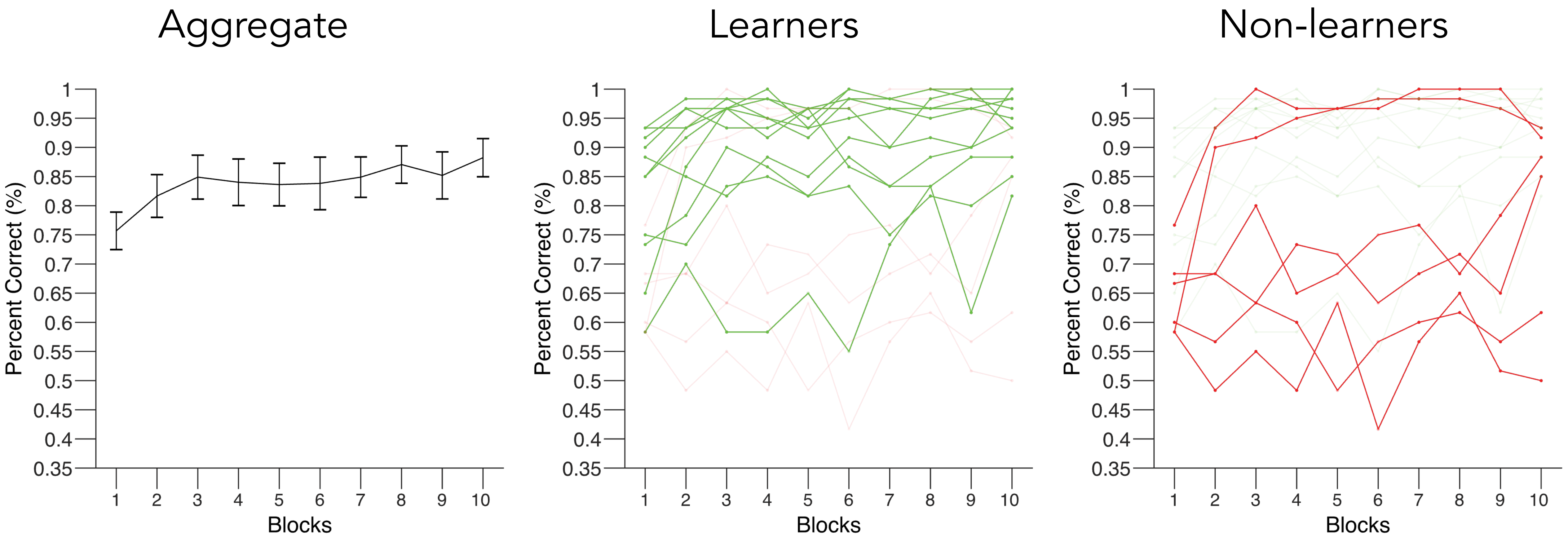
Awareness Test



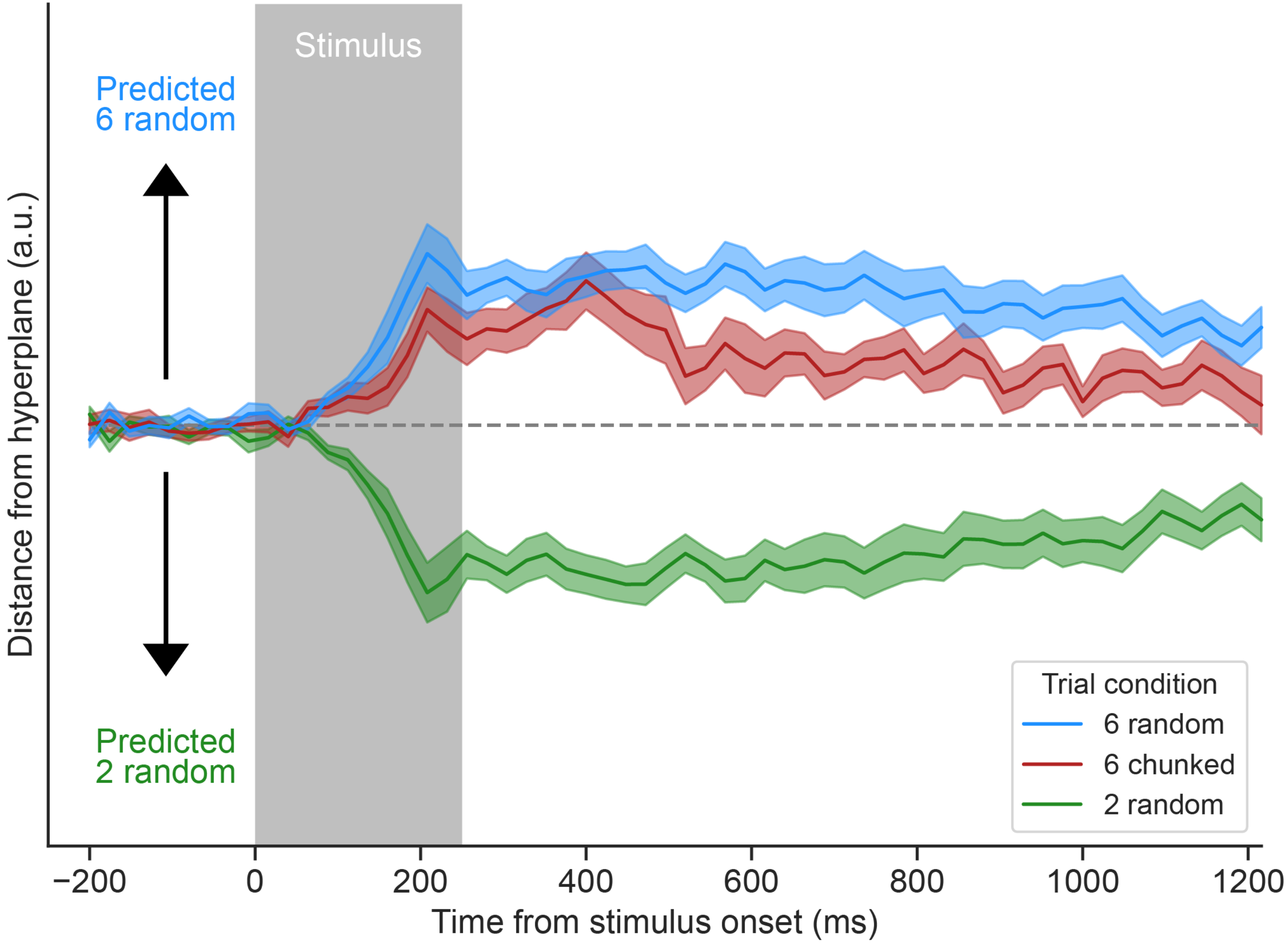
Awareness Test

- Only subjects who correctly produced all triplets were considered "learners"

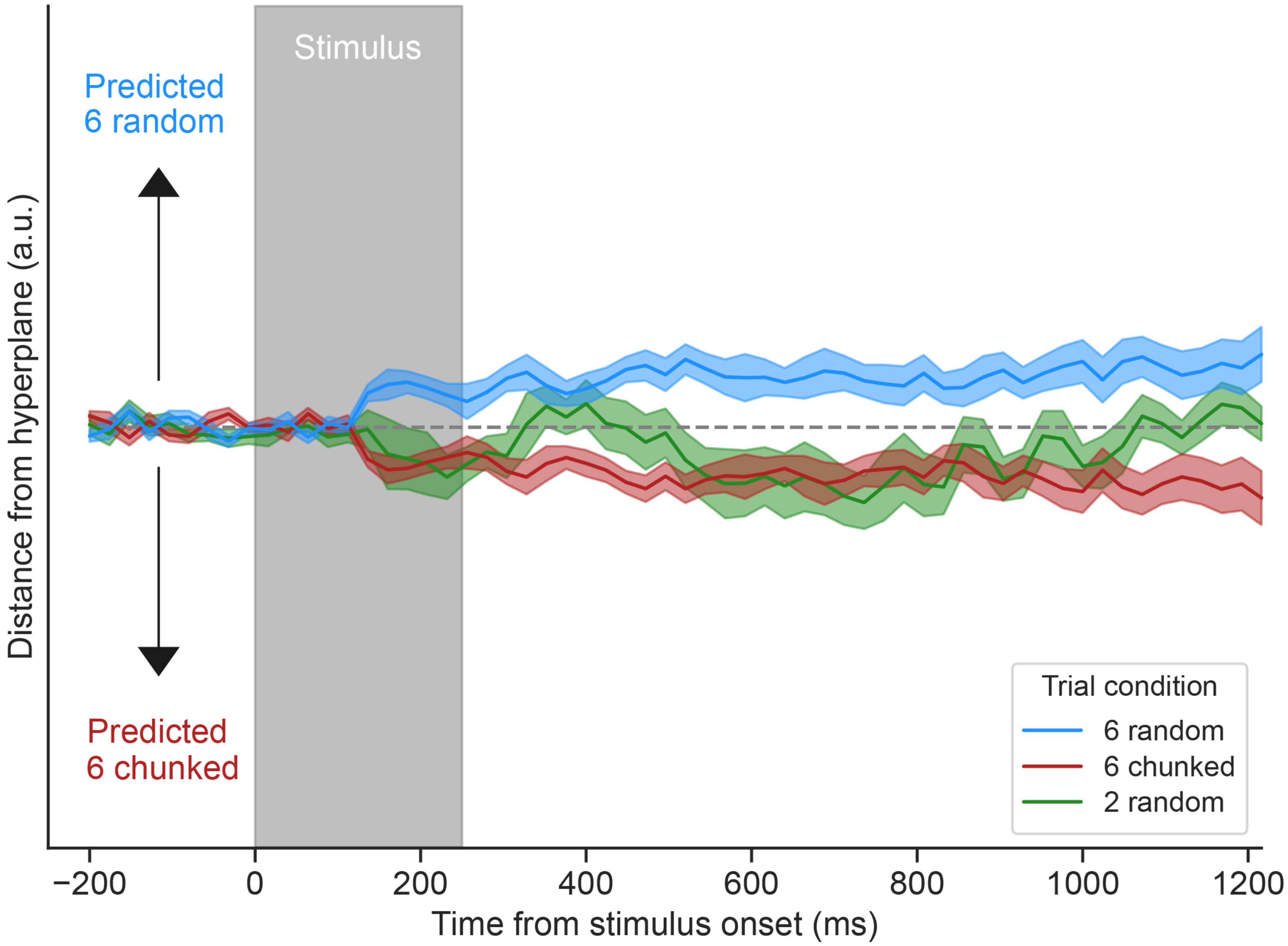
Experiment 2 Training



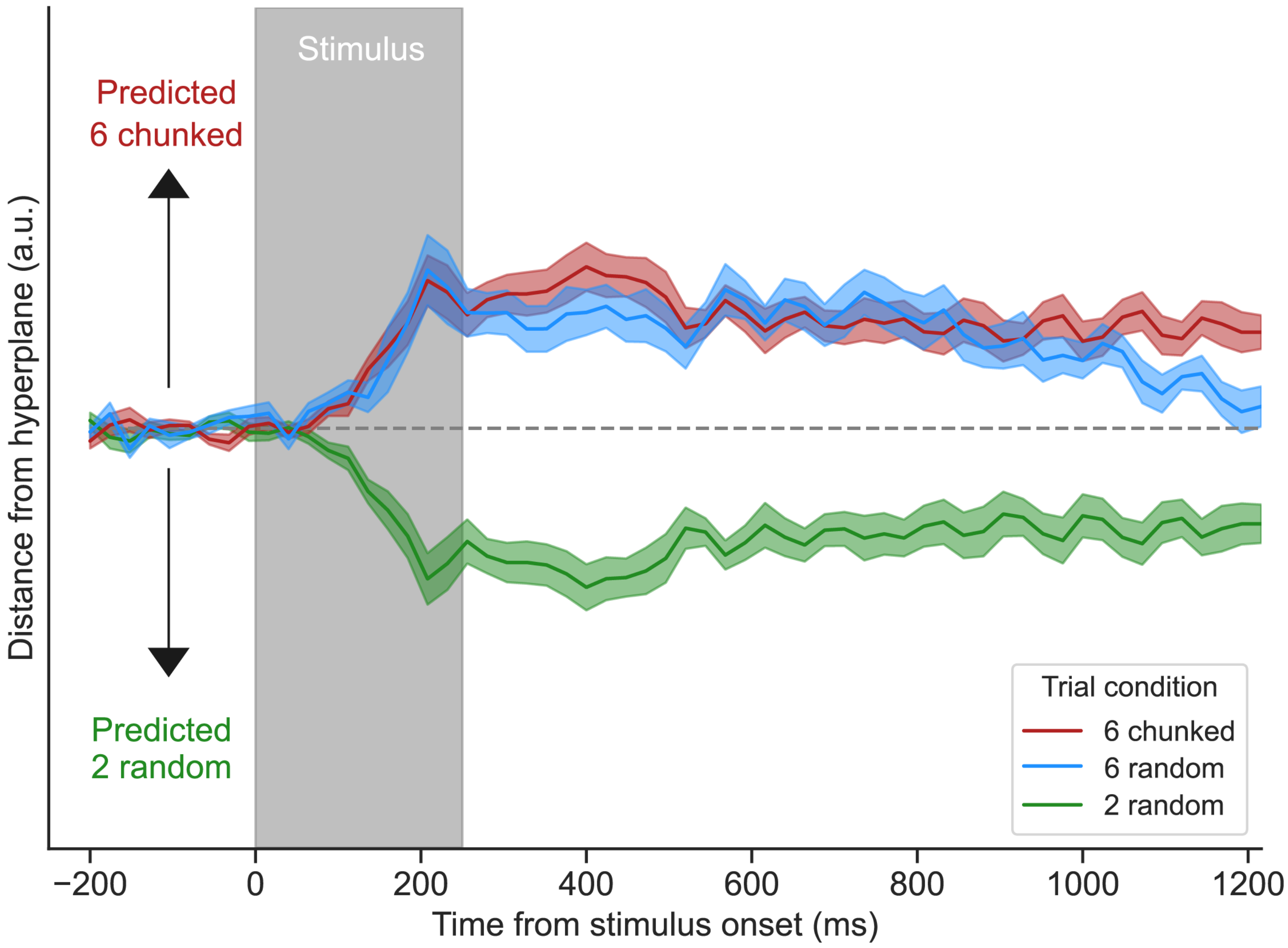
Train 6 random versus 2 random, test 6 chunked



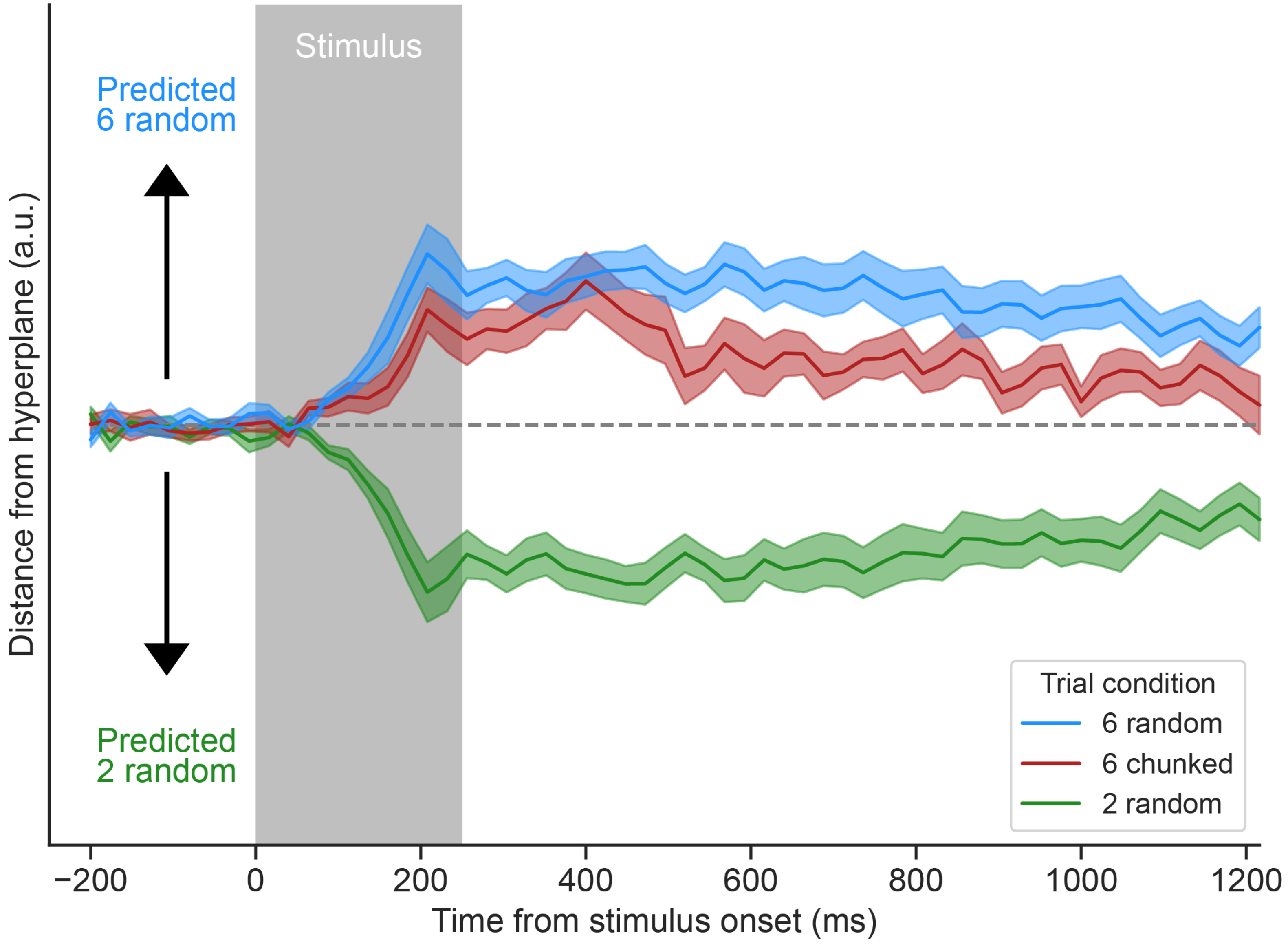
Train 6 random versus 6 chunked, test 2 random



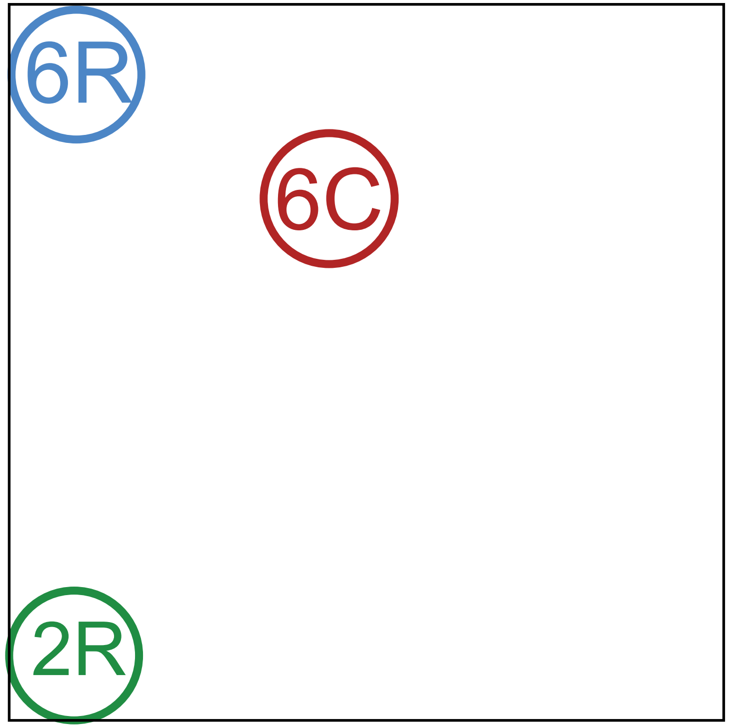
Train 2 random versus 6 chunked, test 6 random



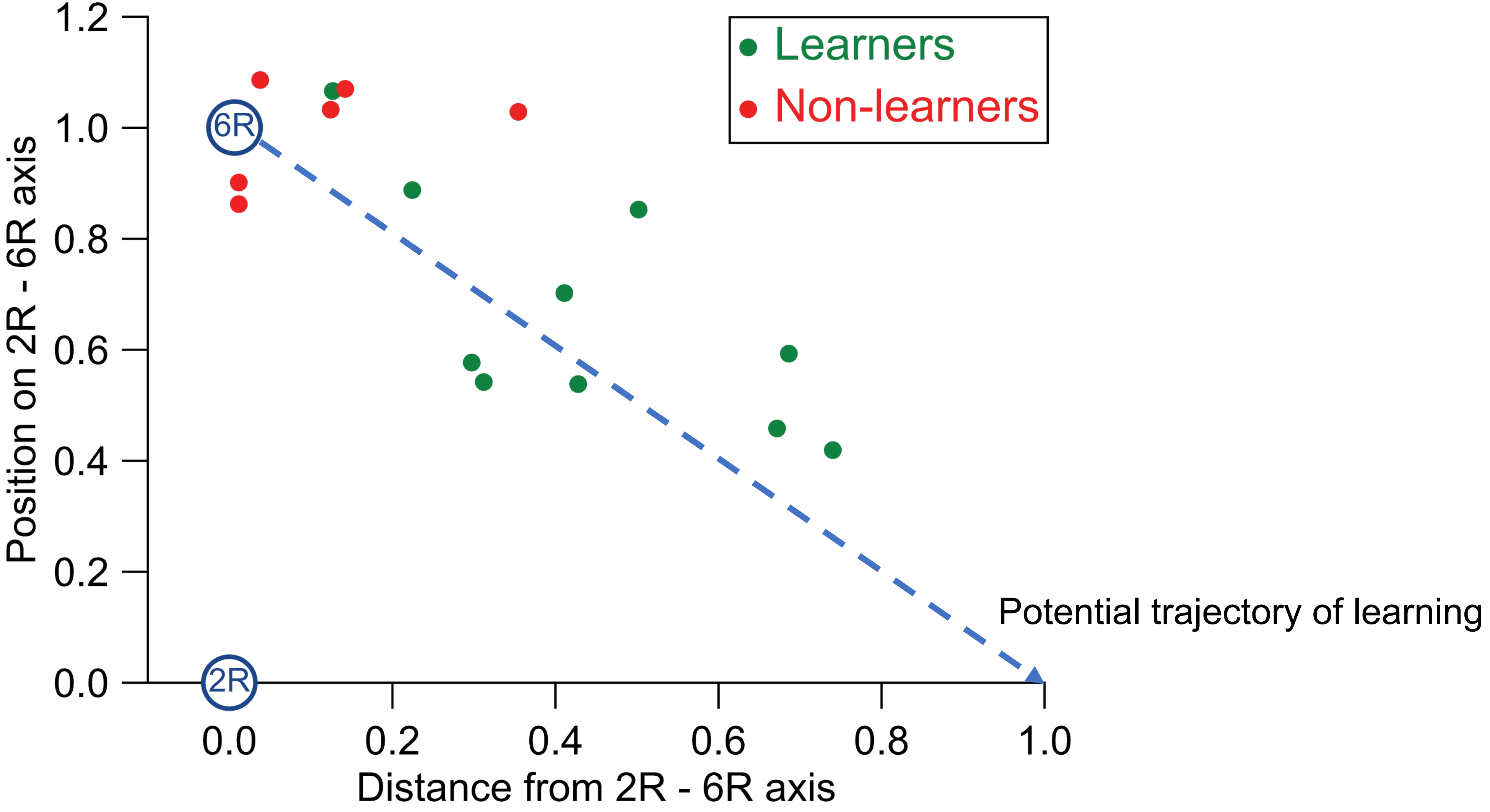
Train 6 random versus 2 random, test 6 chunked



Multidimensional scaling



Multidimensional scaling on each subject



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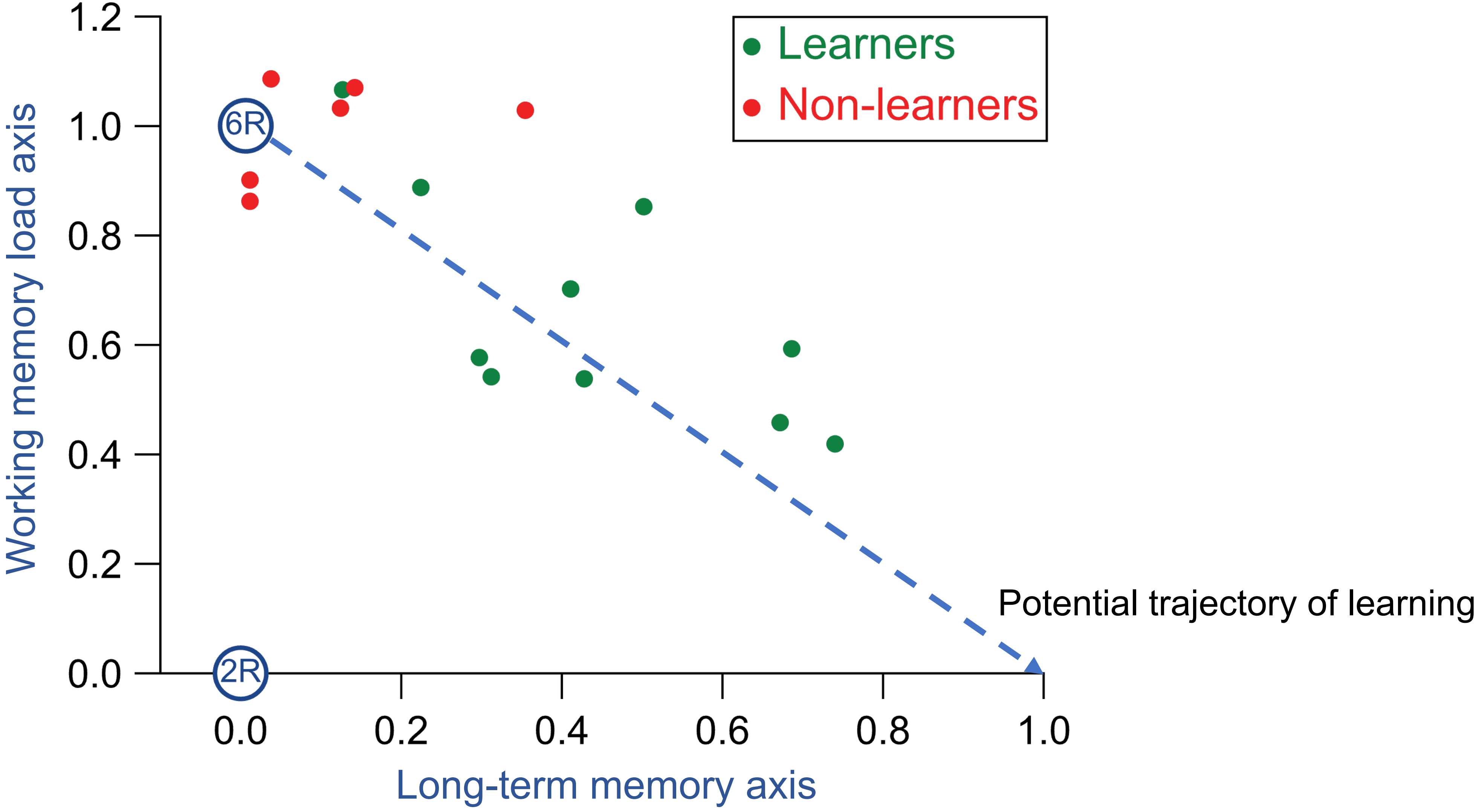
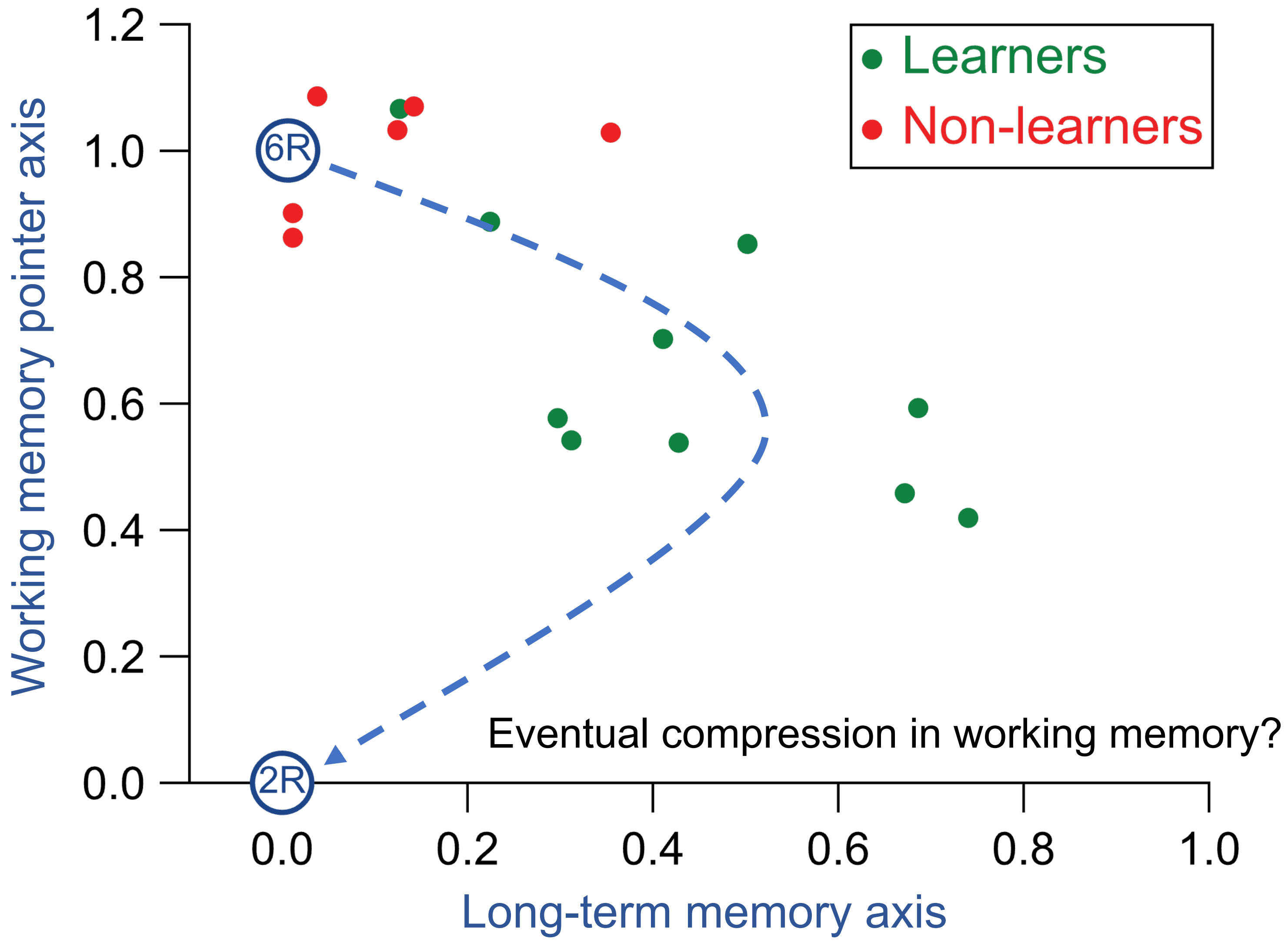


Multidimensional scaling on each subject



Conclusions

- We asked whether associative learning:
  - Increases the number of individuated representations in working memory (memory compression)
  - Or enables items to be chunked reducing the number of items stored in working memory

- A multivariate neural signal for items in working memory shows associative learning ***reduces*** the number of items stored in working memory
- Furthermore, neural signatures of associative learning showed the reduction only in those that successfully learnt the association

- This falls in line with a ***chunking*** account – associative learning does not allow one to circumvent item limits

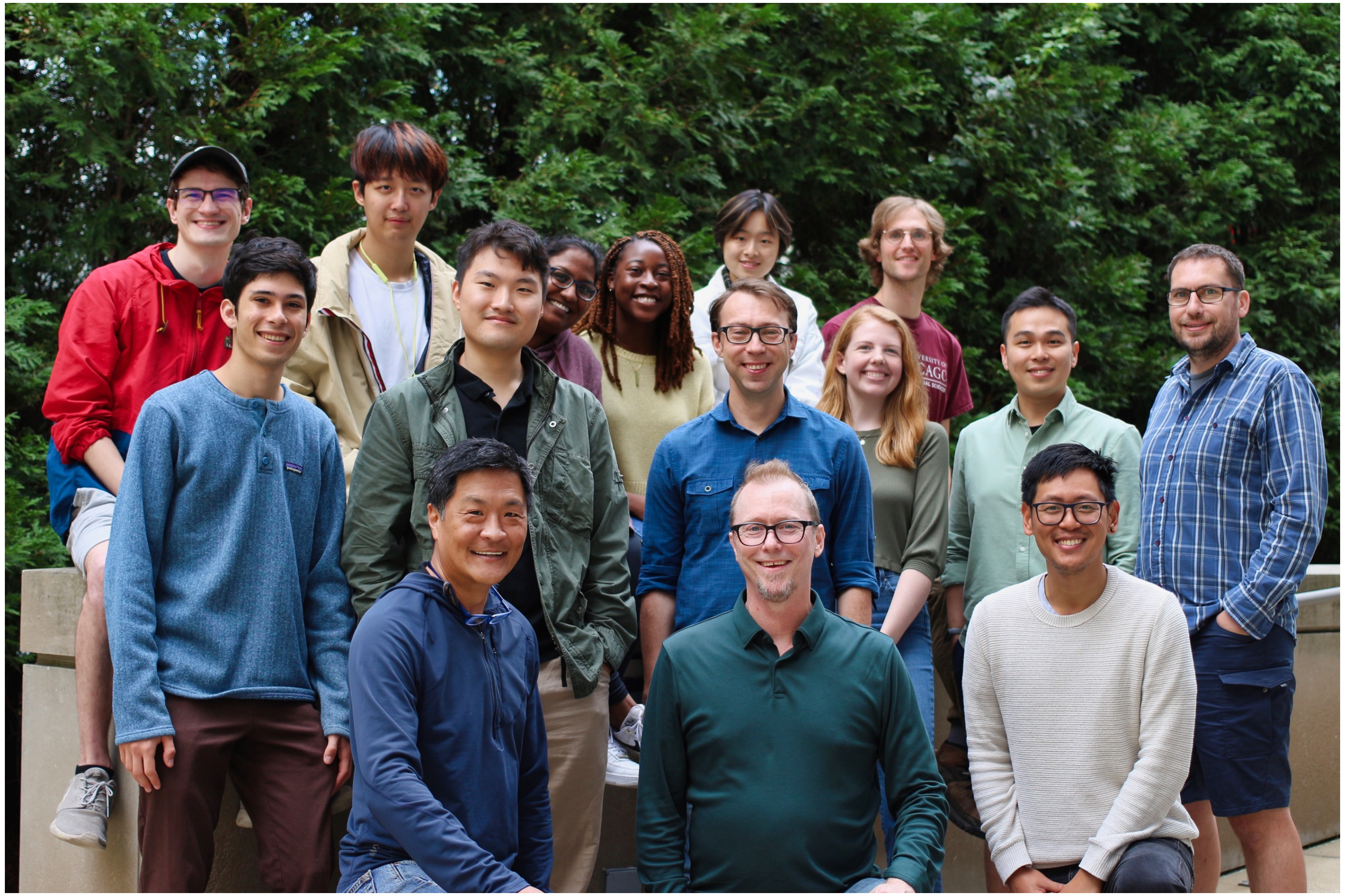
William Thyer

Henry Jones

Darius Suplica

Will Epstein

Edward Awh



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