

# Similarity judgments and visual working memory do not share the same cognitive representation

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# The representation in classic cognitive models

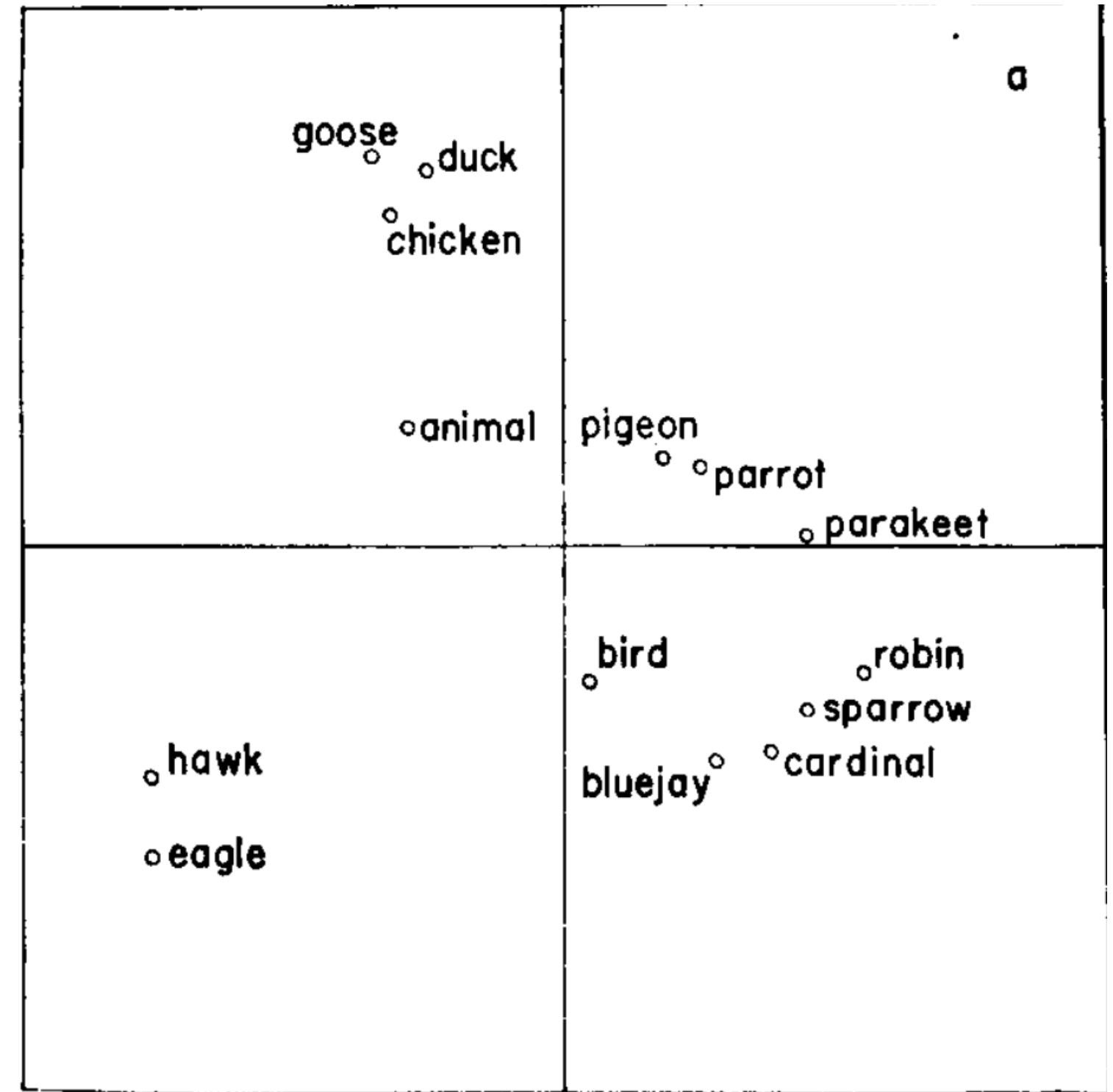
Classic formal models of cognition would derive the **psychological representation** using multidimensional scaling (MDS) of similarity judgments.

- Collect similarity ratings for pairs of items in the stimulus set
- Reduce those ratings into a representation that best preserves the distance between the items; the closer the items, the more similar.

# The representation in classic cognitive models

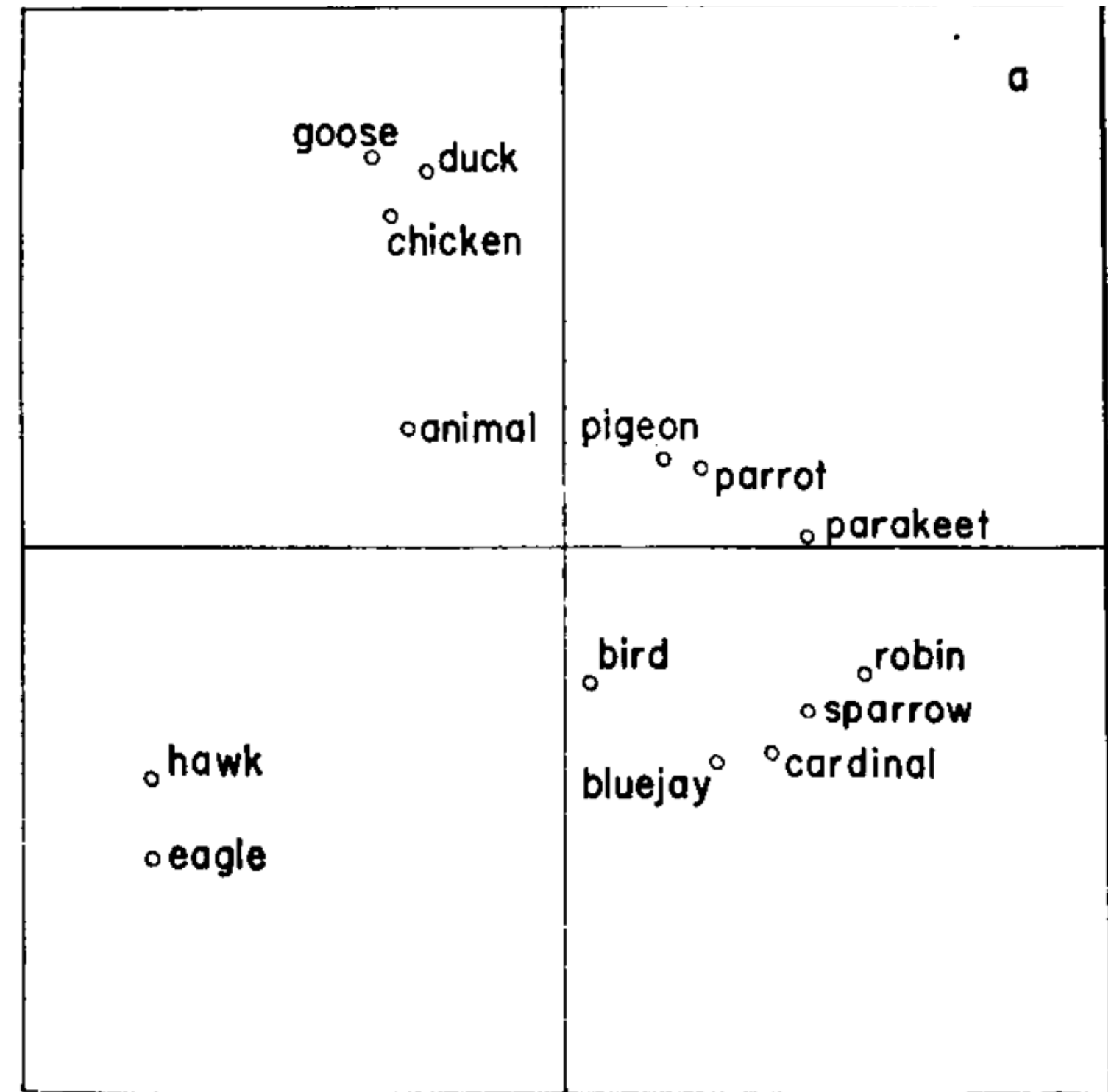
This is the MDS representation  
for **birds**.

The distances between the birds  
reflect their psychological  
similarity; the closer, the more  
similar.



# The representation in classic cognitive models

Formal models use these distances to predict behaviour (such as induction and generalisation).



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do you think **geese** are also susceptible?

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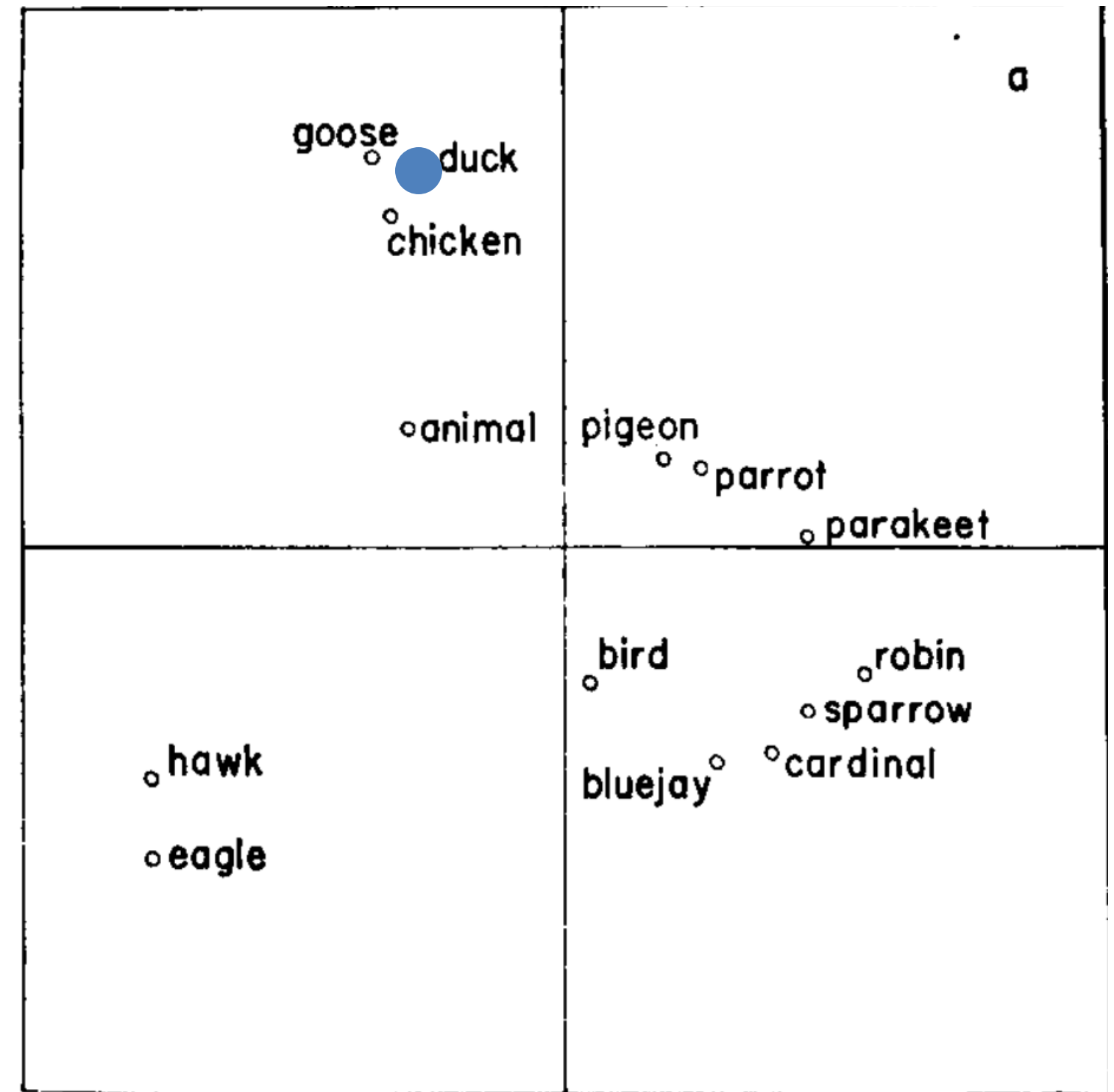
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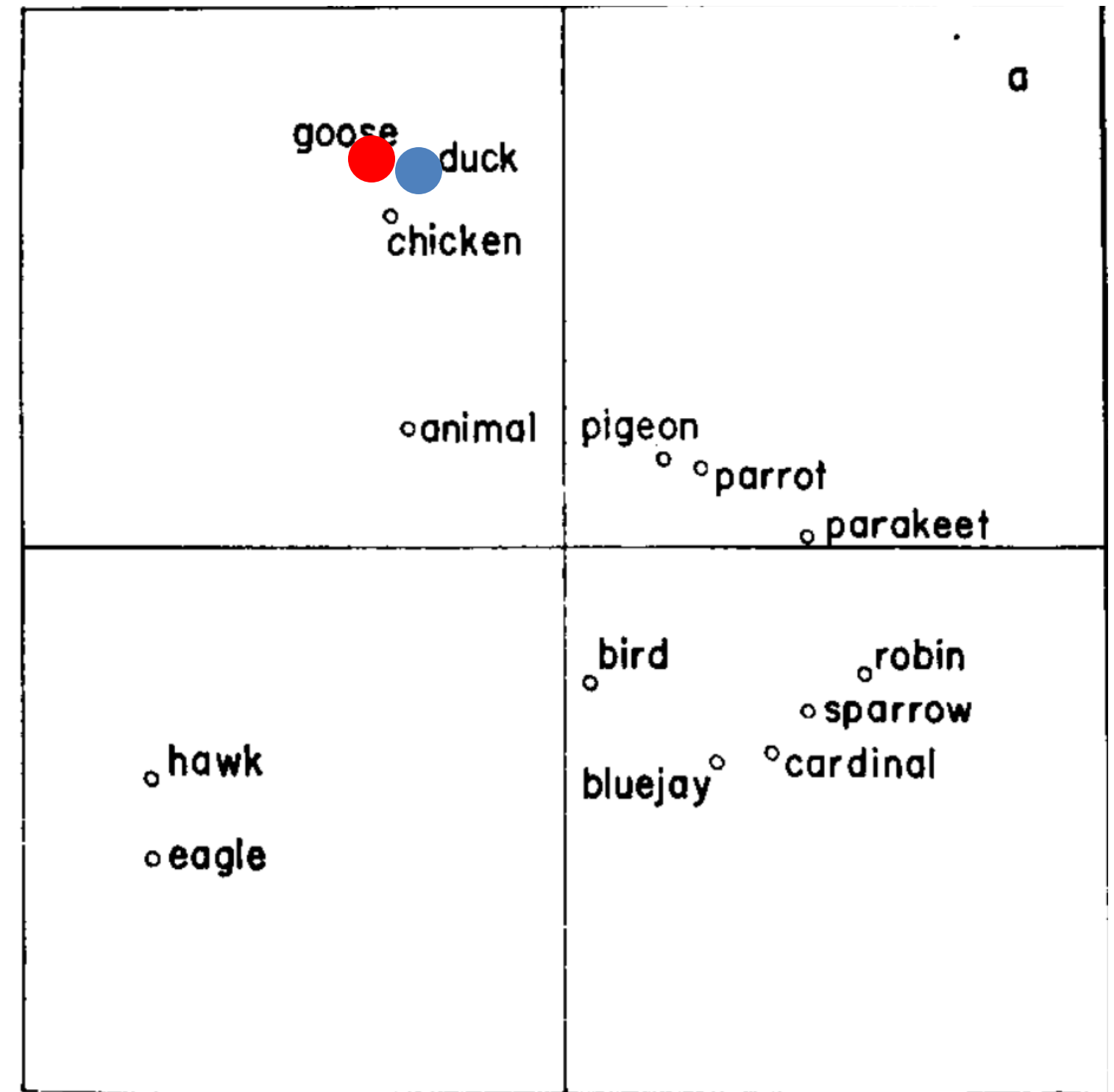




# The representation in classic cognitive models

Formal models use these distances to predict behaviour (such as induction and generalisation).

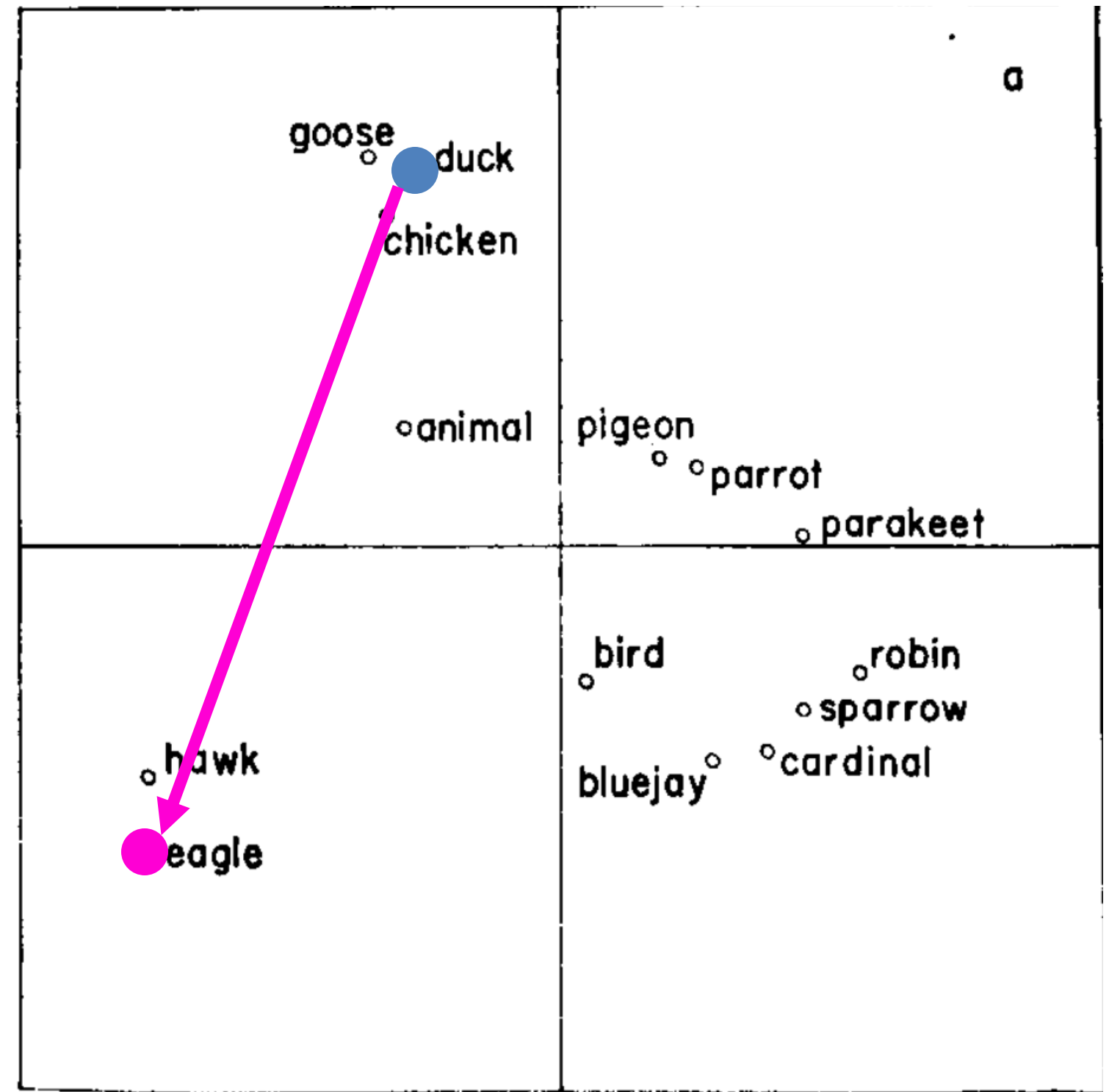
For example, say **ducks** are susceptible to Reinhold disease... one is likely to think **geese** are also susceptible.



# The representation in classic cognitive models

Formal models use these distances to predict behaviour (such as induction and generalisation).

For example, say **ducks** are susceptible to Reinhold disease... but less likely to think **eagles** are also susceptible.



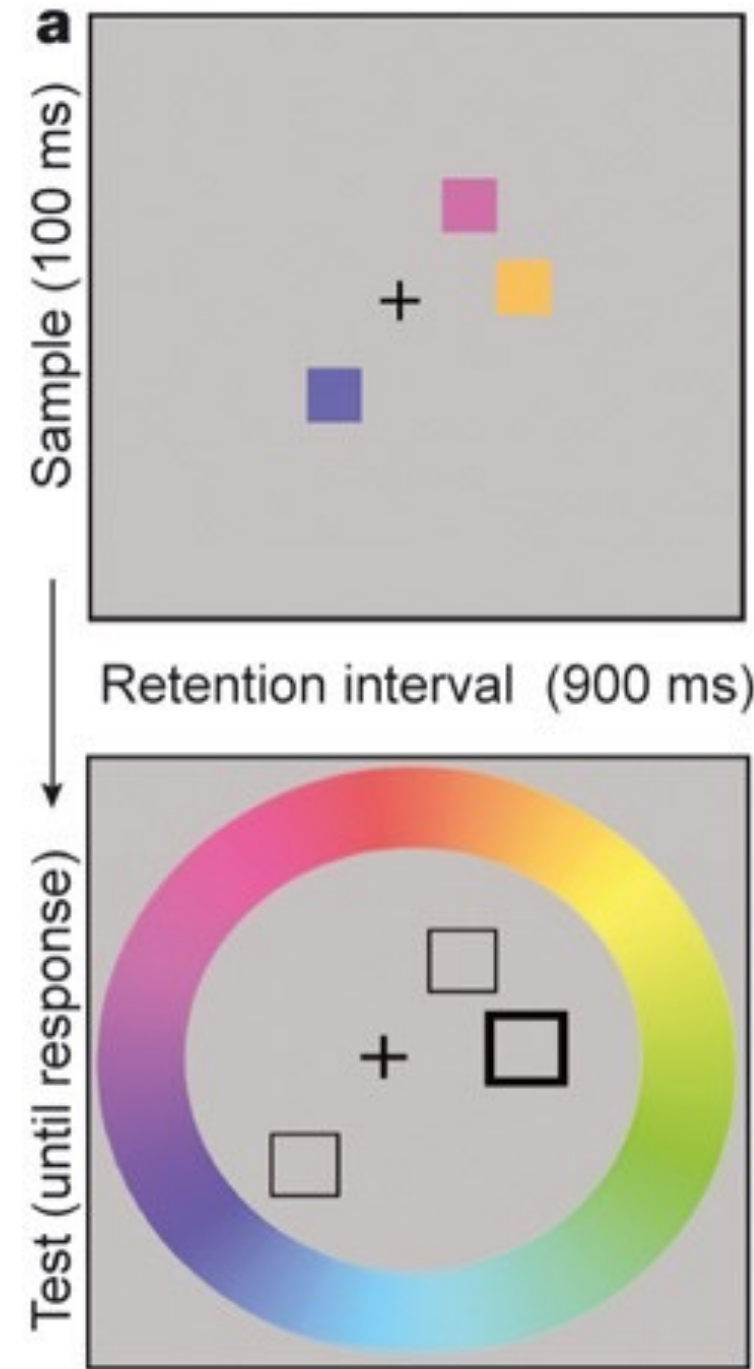
# The representation in classic cognitive models

For historical reasons, the similarity-based MDS-representation has been considered **the psychological representation** underlying cognition.

Many cognitive modelers focus on the operations that occur on the representation, rather than explain the representation itself.

# Two classes of visual working memory models

Most visual working memory models assume **the physical stimulus space** as the representation that cognitive mechanisms operate upon.



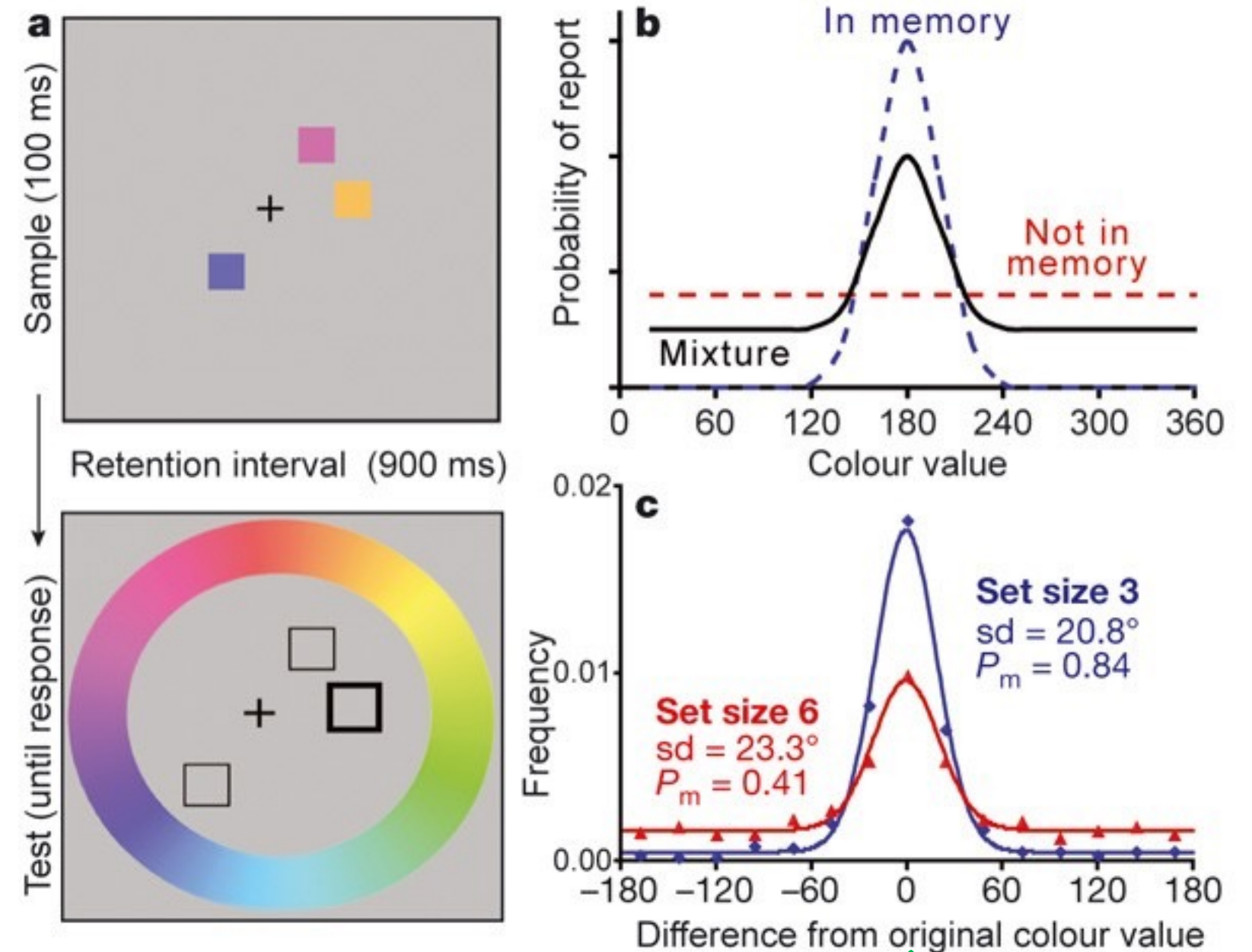
Models assume the physical space, such as this colour wheel



# Two classes of visual working memory models

Most visual working memory models assume **the physical stimulus space** as the representation that cognitive mechanisms operate upon.

Memory operationalised in terms of absolute error on colour wheel

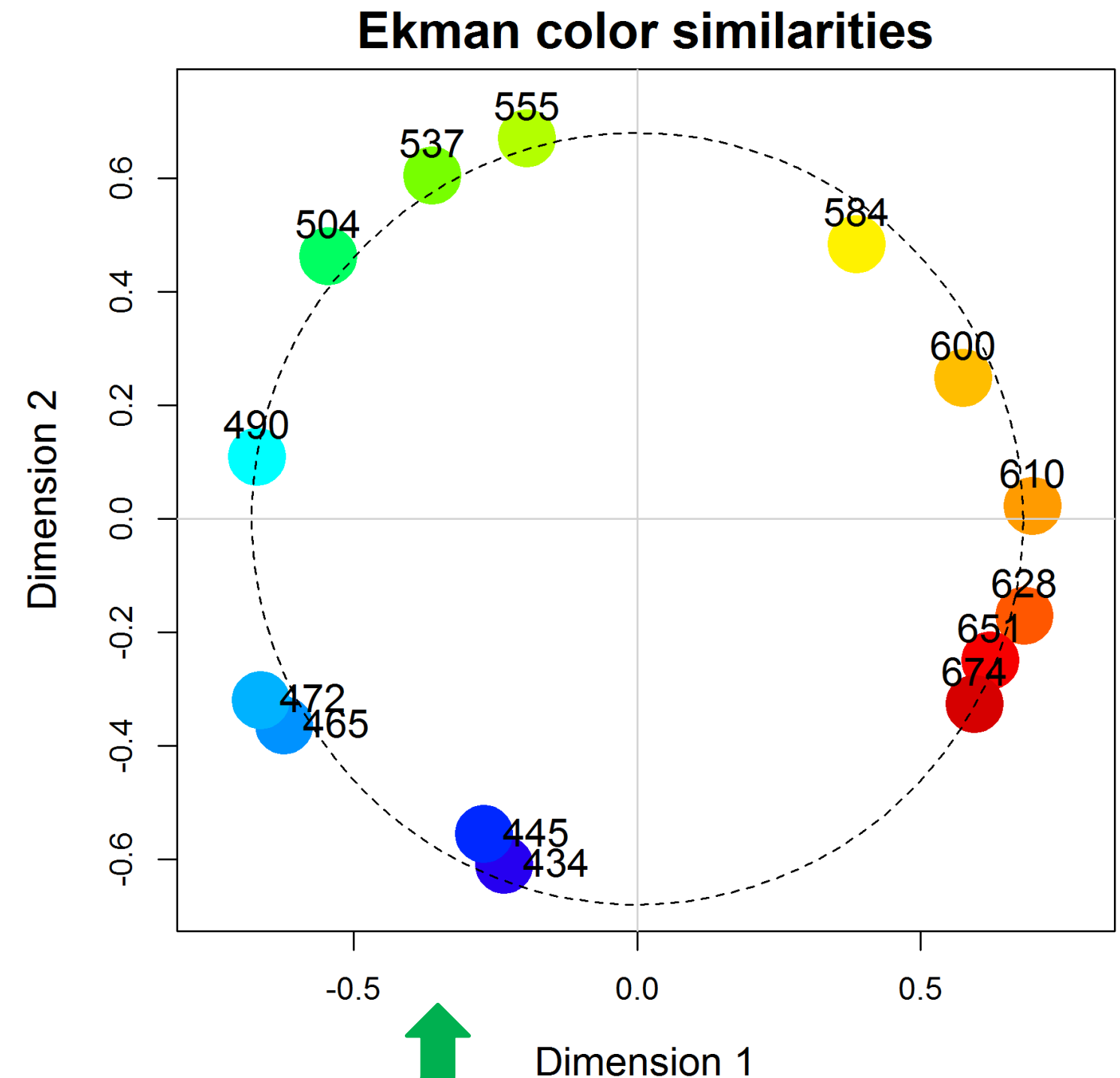




# The representation in visual working memory

A recent model (the TCC model; Schurgin et al., 2020) argued that working memory is best modelled in terms of **psychological similarity**.

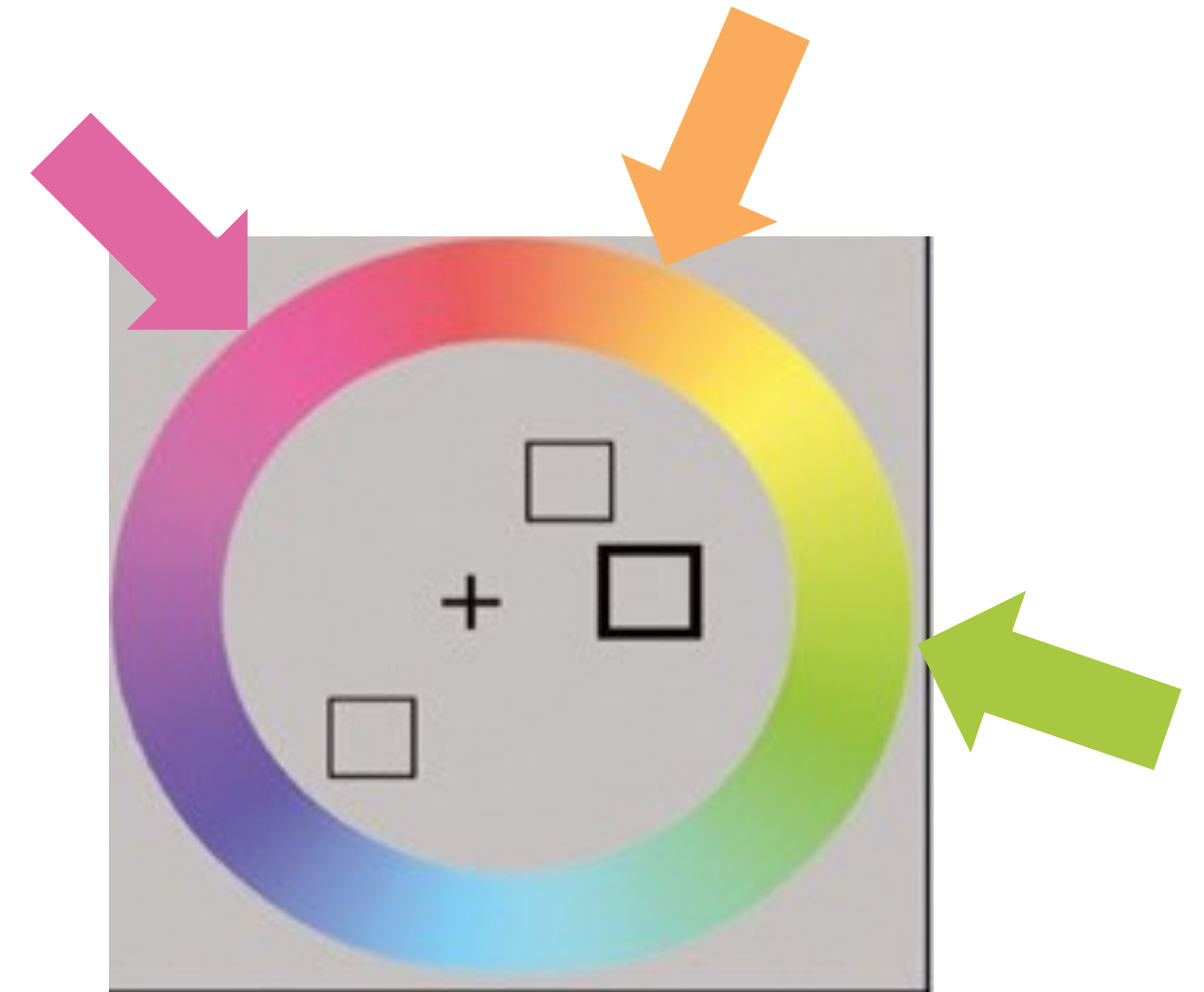
Similarity-based MDS-representation of colours



# The representation in visual working memory

They made the point that confusability would not be captured on the physical stimulus space.

For example, **orange** is more similar to **pink** than **green**, despite being the same distance in absolute degrees.



# The representation in visual working memory

Recent work has found that adjustments for psychological similarity do not improve model fits for visual working memory performance.

But there remain issues with assuming the physical stimulus space or the similarity-based space to build cognitive models.

Thus, the question remains – **what is the representation underlying visual working memory?**

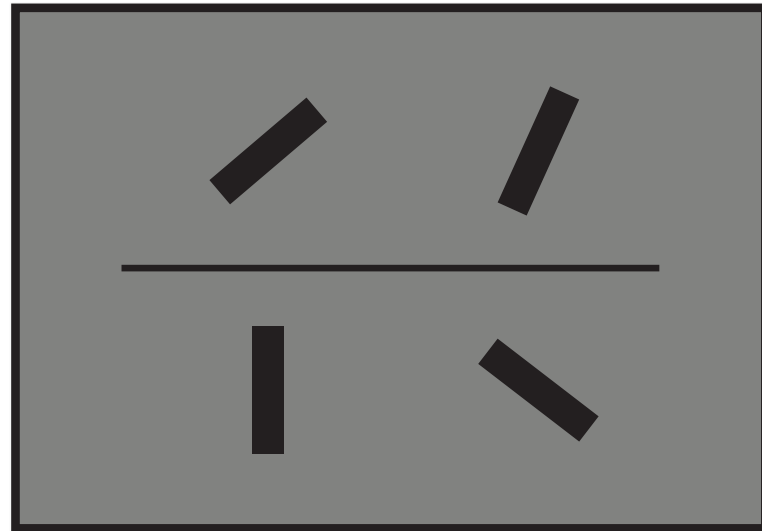


# Our modeling approach

In brief, we used Bayesian MCMC methods to recover the **latent representation** underlying three cognitive tasks using oriented lines. The data comes from an open dataset (Tomic and Bays, 2024).

# The cognitive tasks

a

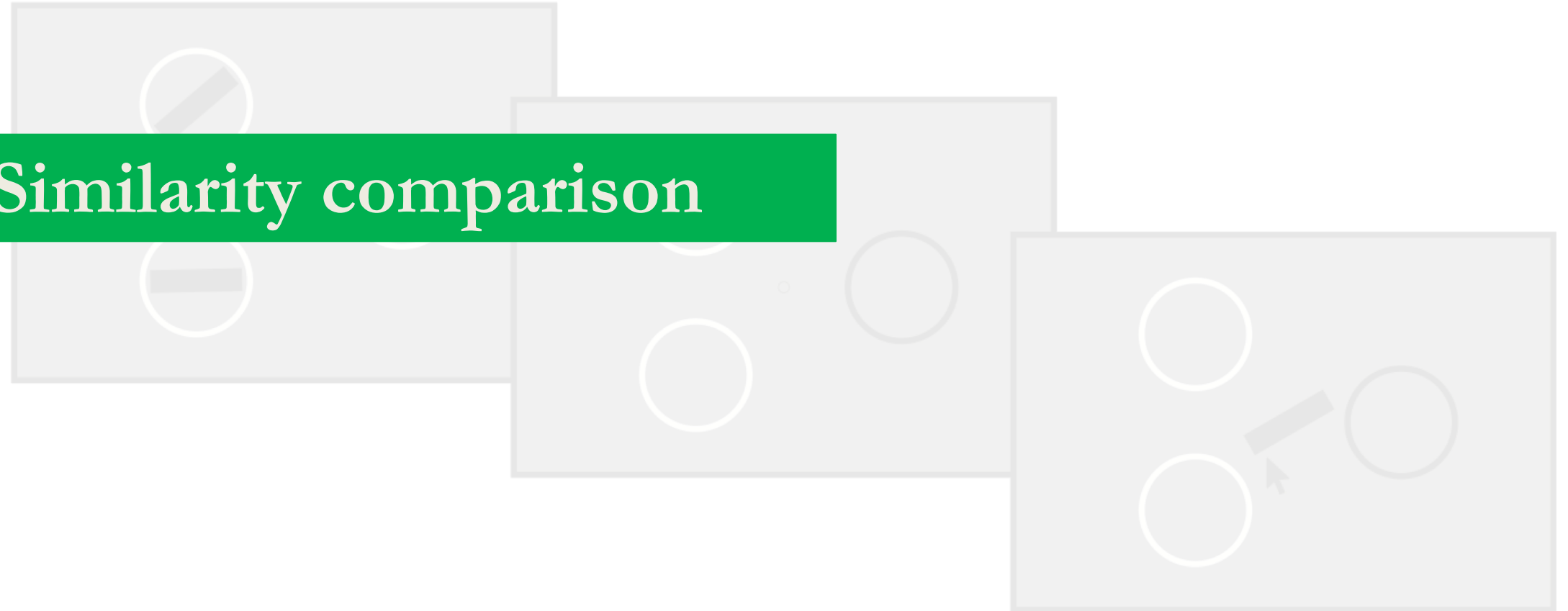


b

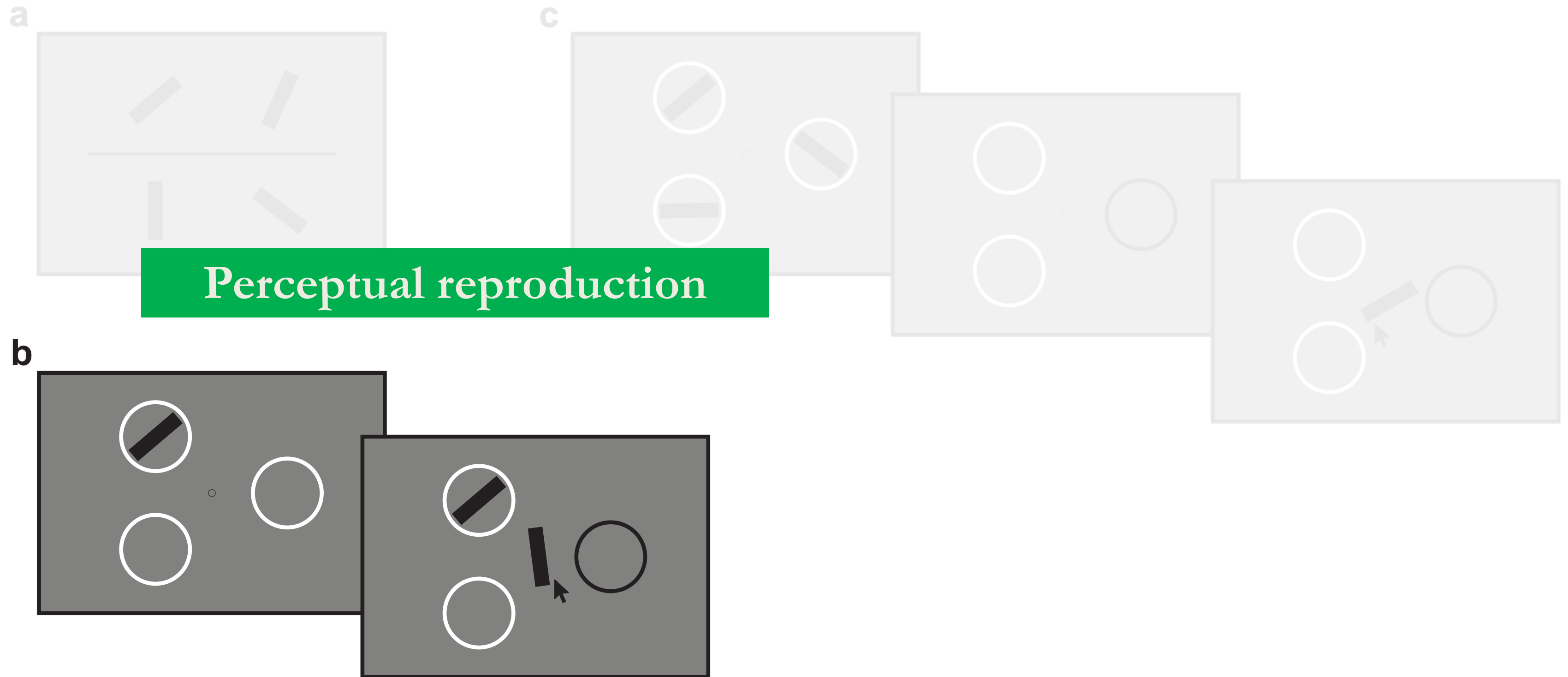


c

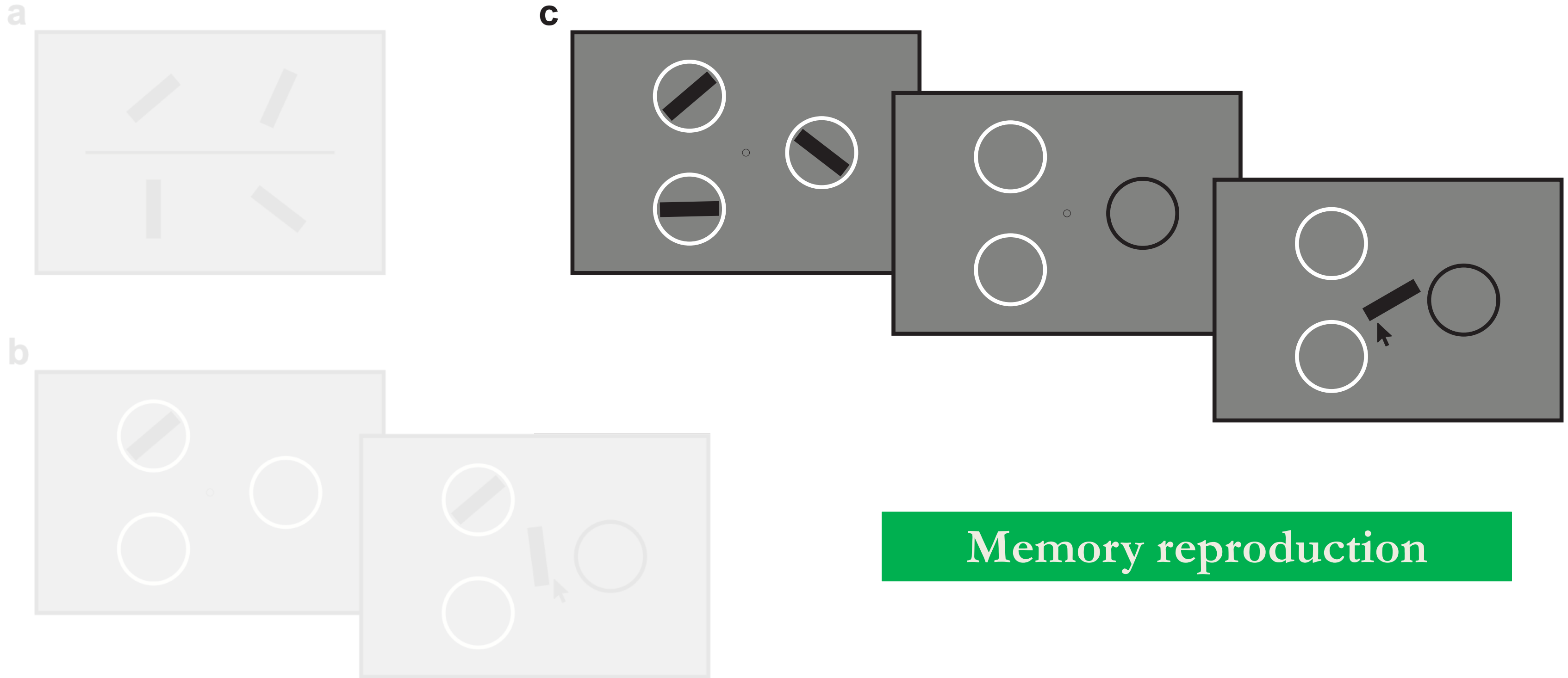
Similarity comparison



# The cognitive tasks



# The cognitive tasks



Memory reproduction

# Our modeling goal

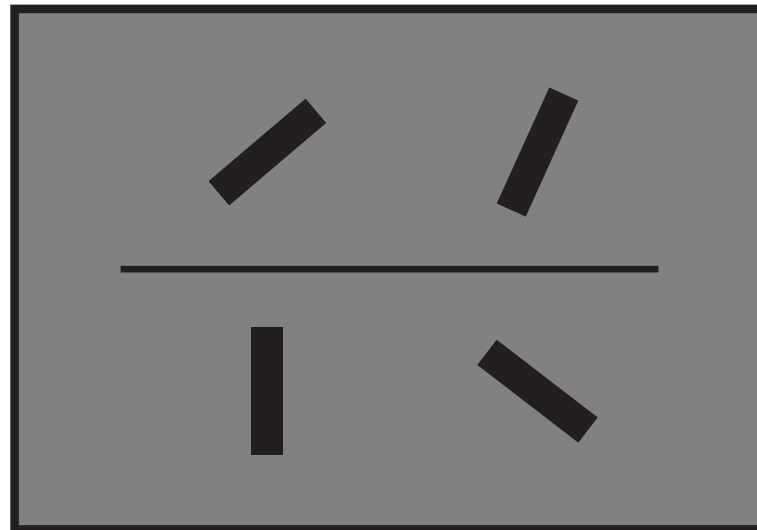
Our goal was to recover the **latent representations** of the orientation stimuli in the three cognitive tasks.

Note that the latent representation is modelled using the task data itself, not outsourced to MDS with similarity judgments.

# Our modeling approach

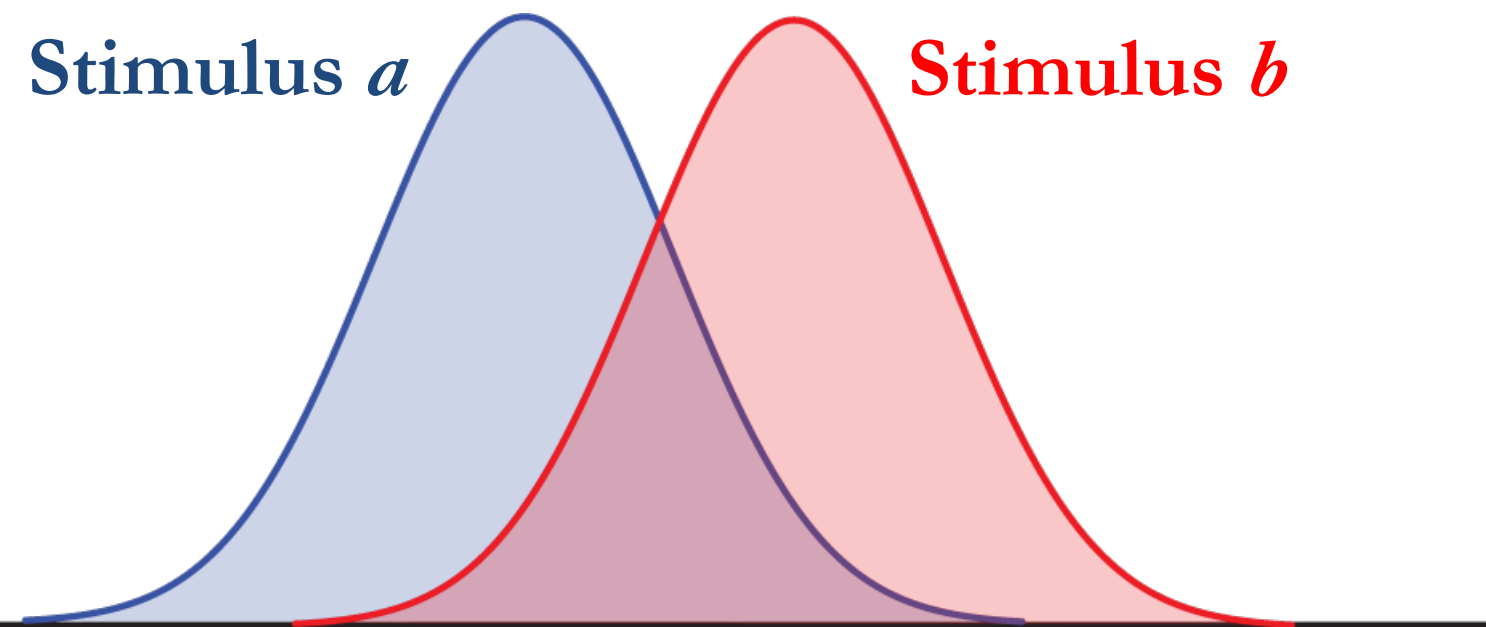
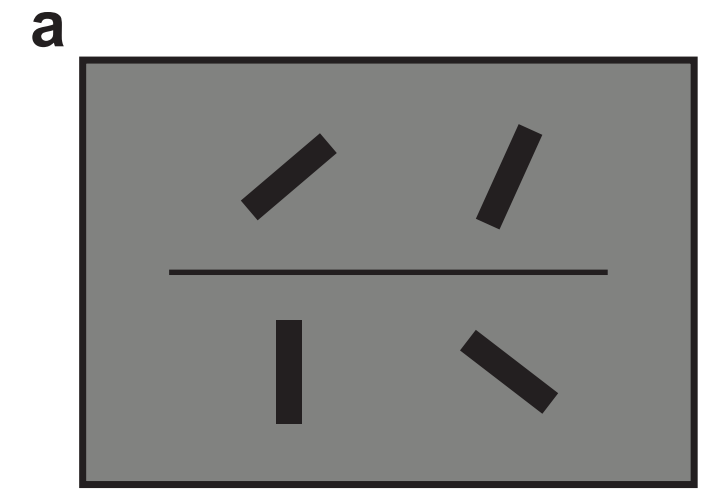
We took a Bayesian generative modeling approach – we built a **Thurstonian model** that infers the underlying representation.

a



Similarity comparison

# Our modeling approach

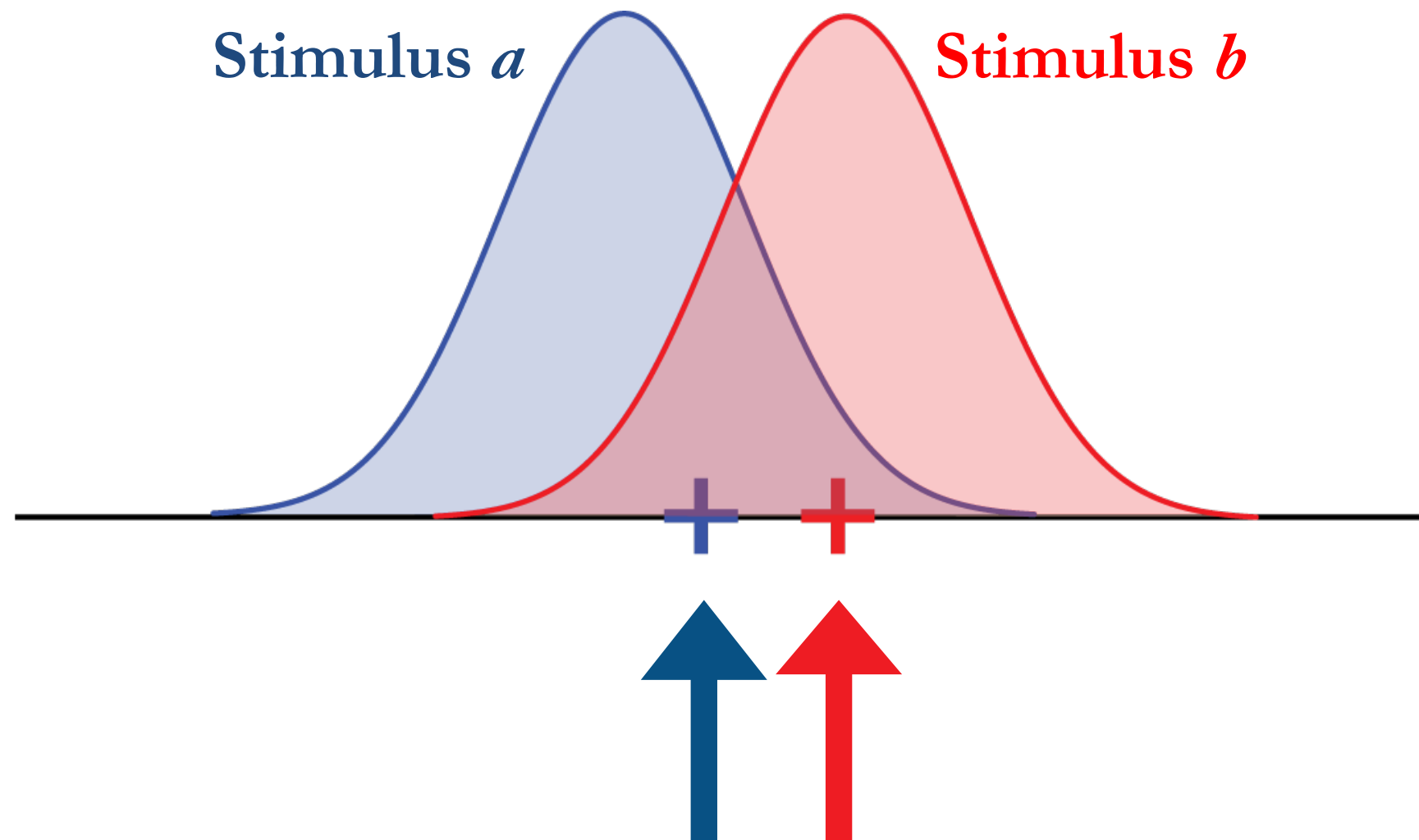
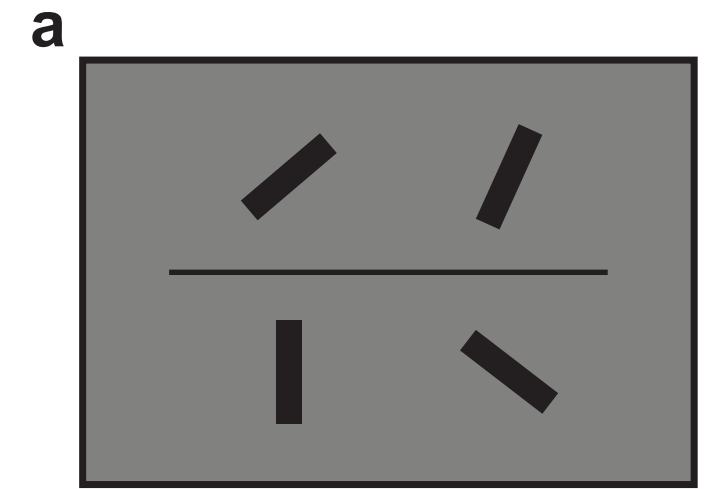


We model the latent representation of each orientation stimulus as a circular Gaussian distribution, centred on a value ( $\mu_n$ ) and with a common width ( $\sigma$ ).

For model identifiability  $\left\{ \begin{array}{l} \mu_1 = 0 \\ \mu_2 \sim \text{uniform}(0, \frac{\pi}{2}) \end{array} \right.$

Uninformed priors  $\left\{ \begin{array}{l} \mu_3, \dots, \mu_n \sim \text{uniform}(0, \pi) \\ \sigma \sim \text{uniform}(0, \pi) \end{array} \right.$

# Our modeling approach



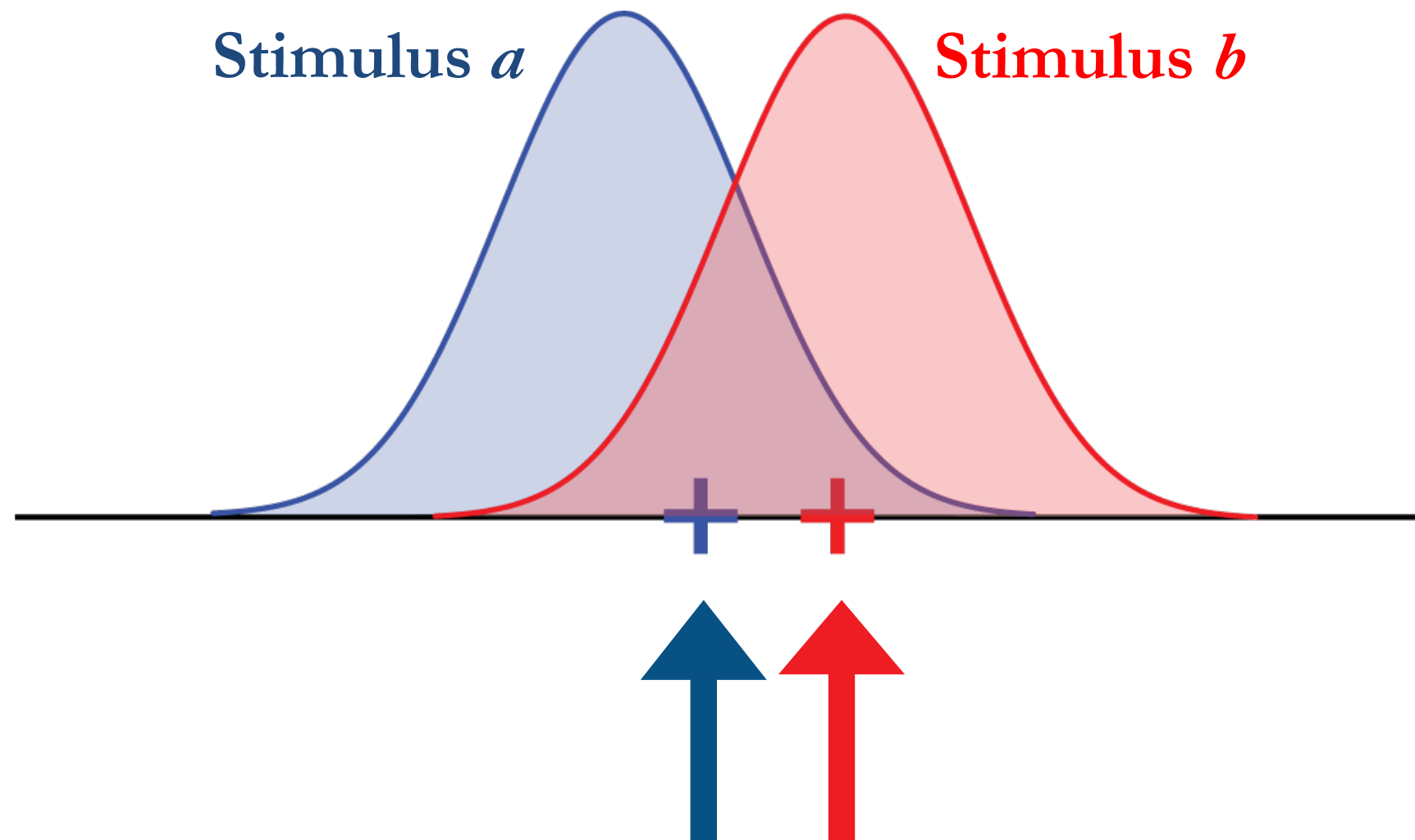
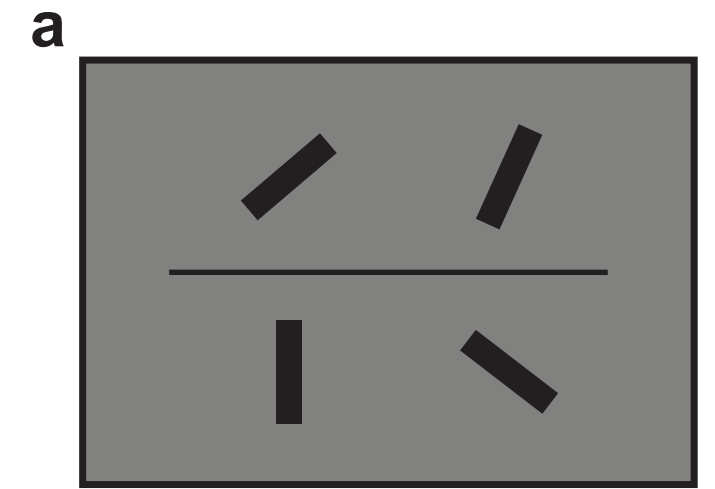
The participant takes one sample from each latent representation of the pair.

$$x_t^a \sim \text{Gaussian}(\mu_{a_t}, \frac{1}{\sigma^2})$$

$$x_t^b \sim \text{Gaussian}(\mu_{b_t}, \frac{1}{\sigma^2})$$



# Our modeling approach



The psychological distance between the pair of stimuli is the distance between the samples

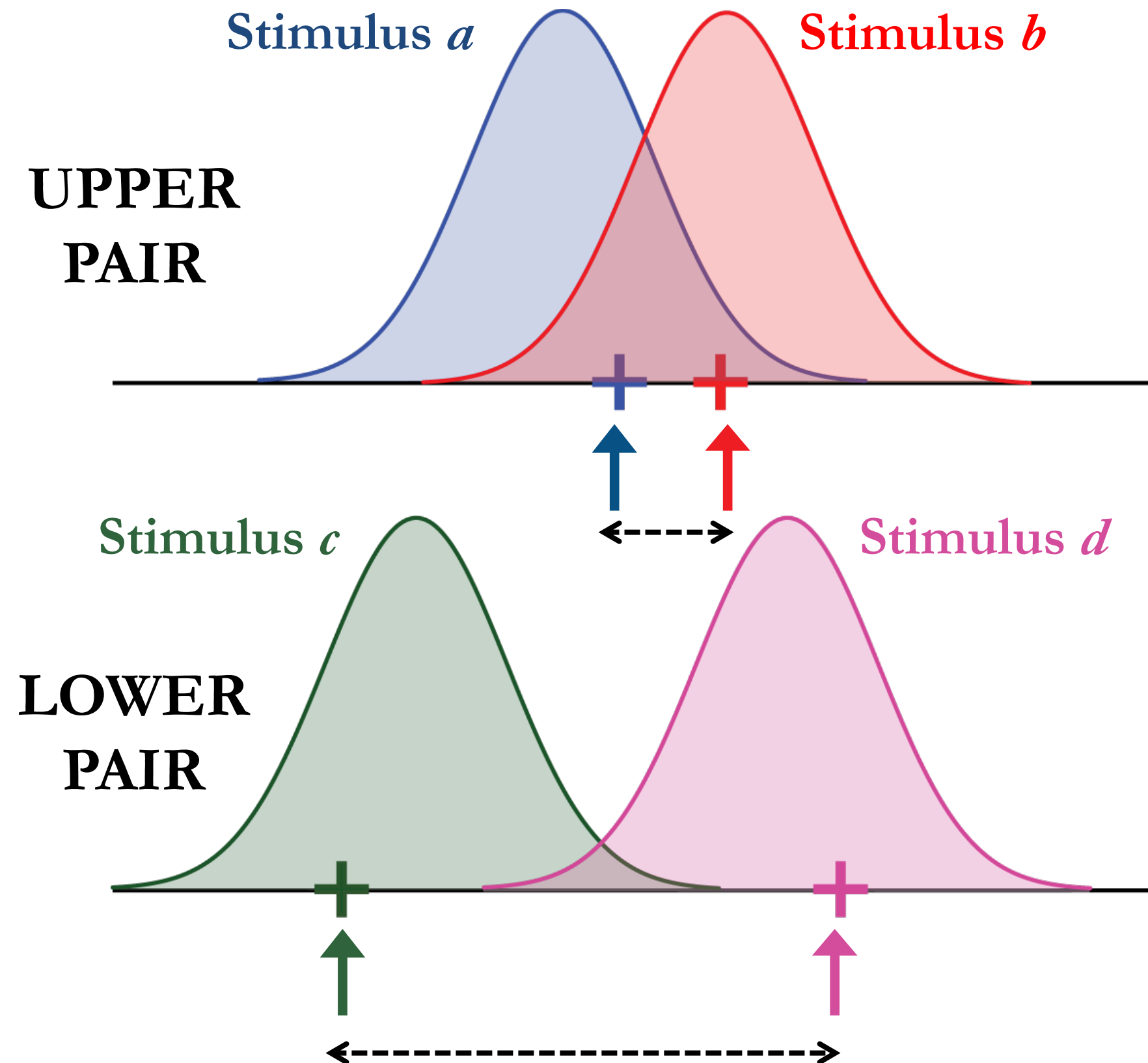
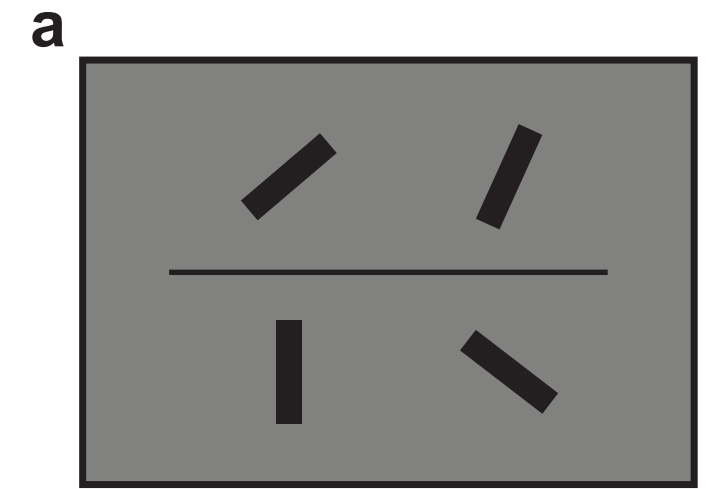


$$d_t^{ab} = \min(|x_t^a - x_t^b|, \pi - |x_t^a - x_t^b|)$$



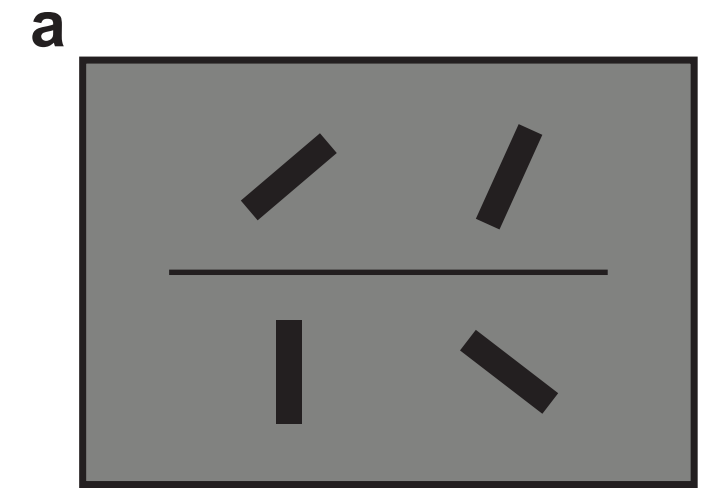
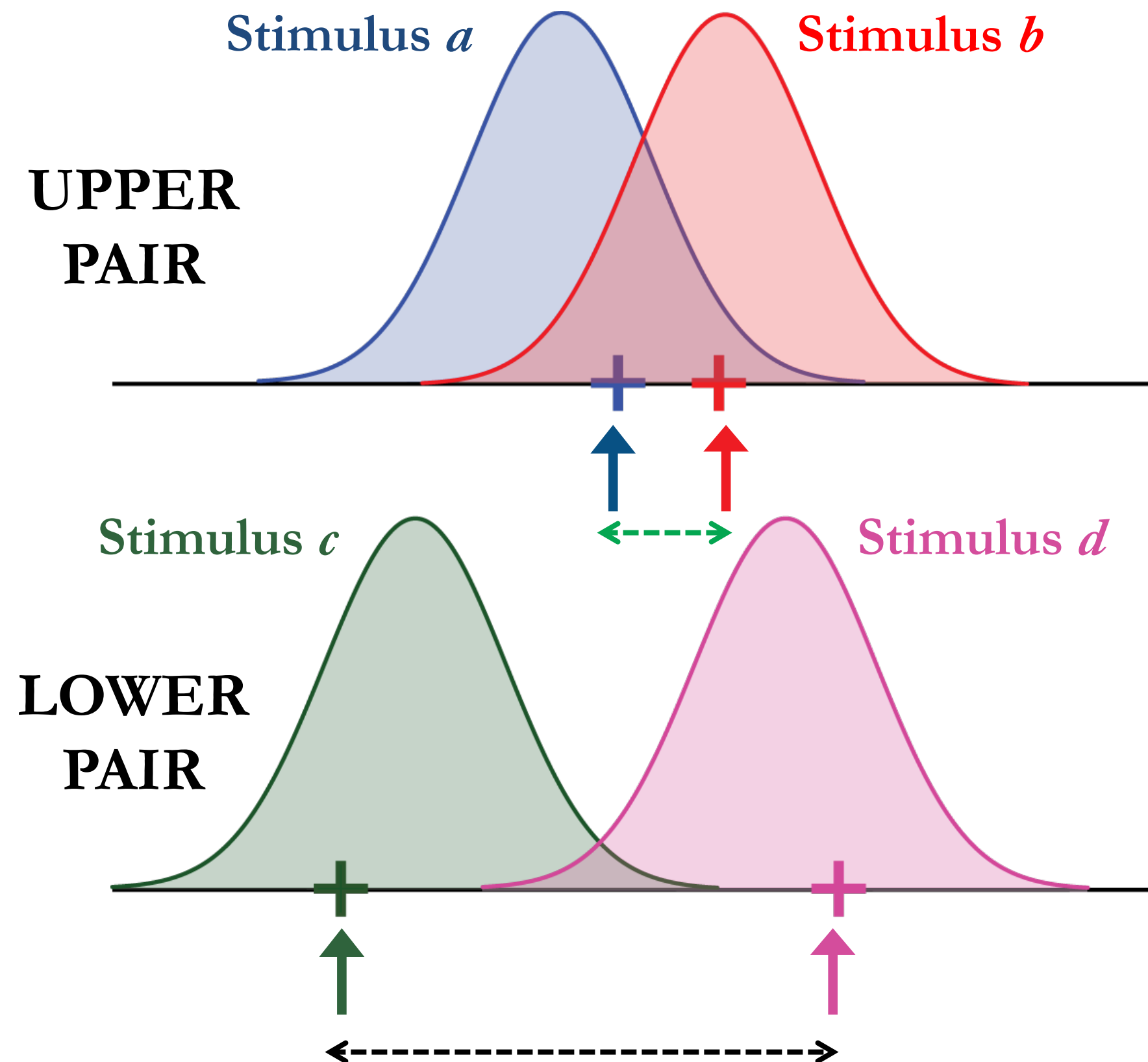
Accounts for  
semi-circular  
nature of angles

# Our modeling approach



Repeat to calculate the psychological distance for the orientation stimuli in the second pair.

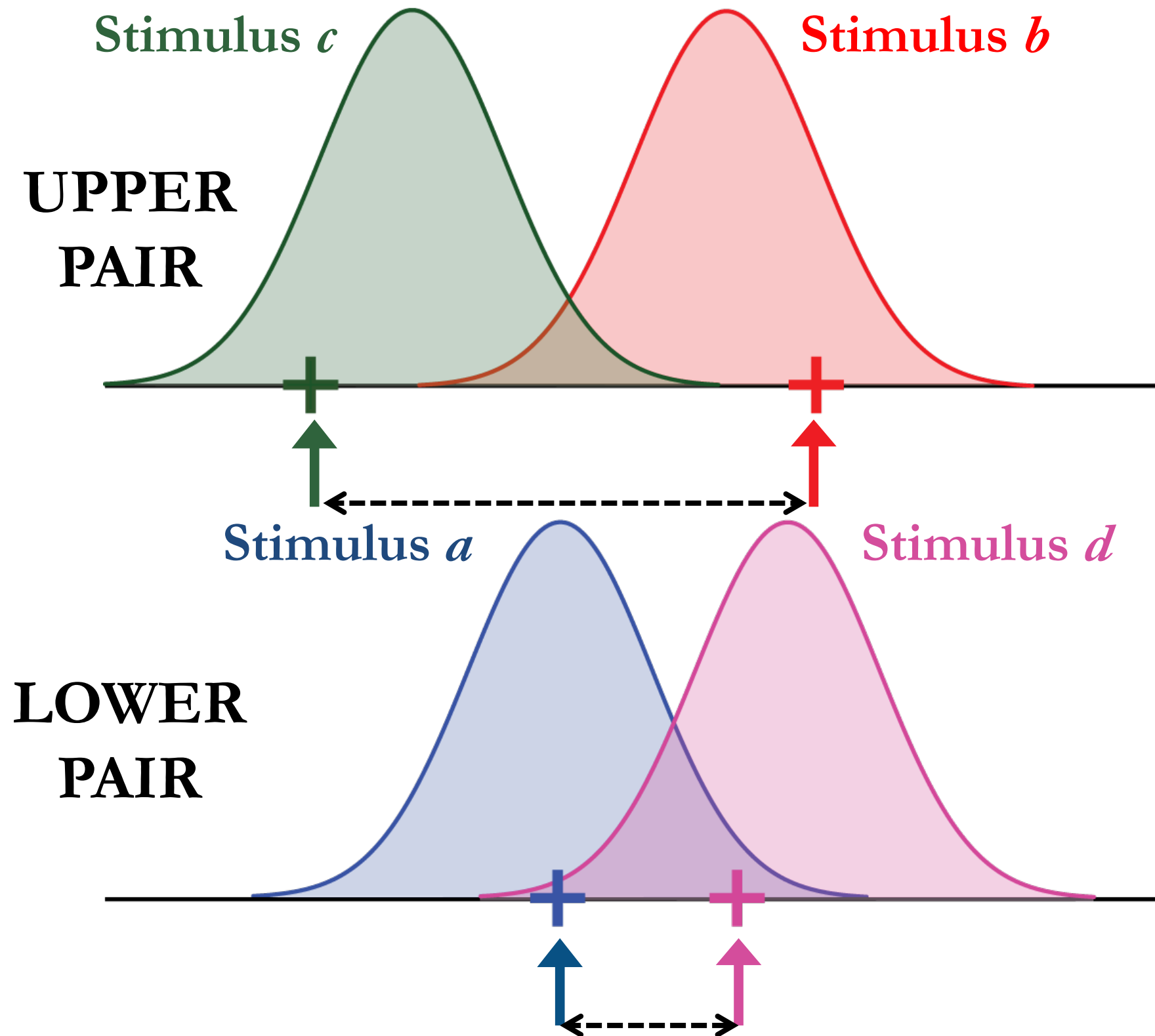
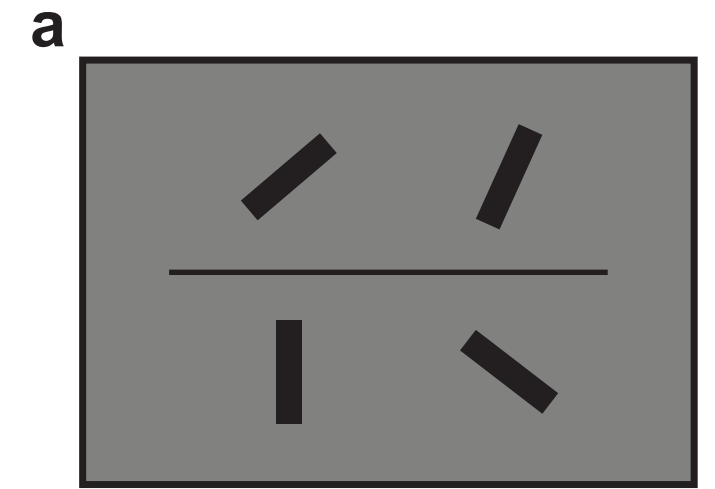
# Our modeling approach



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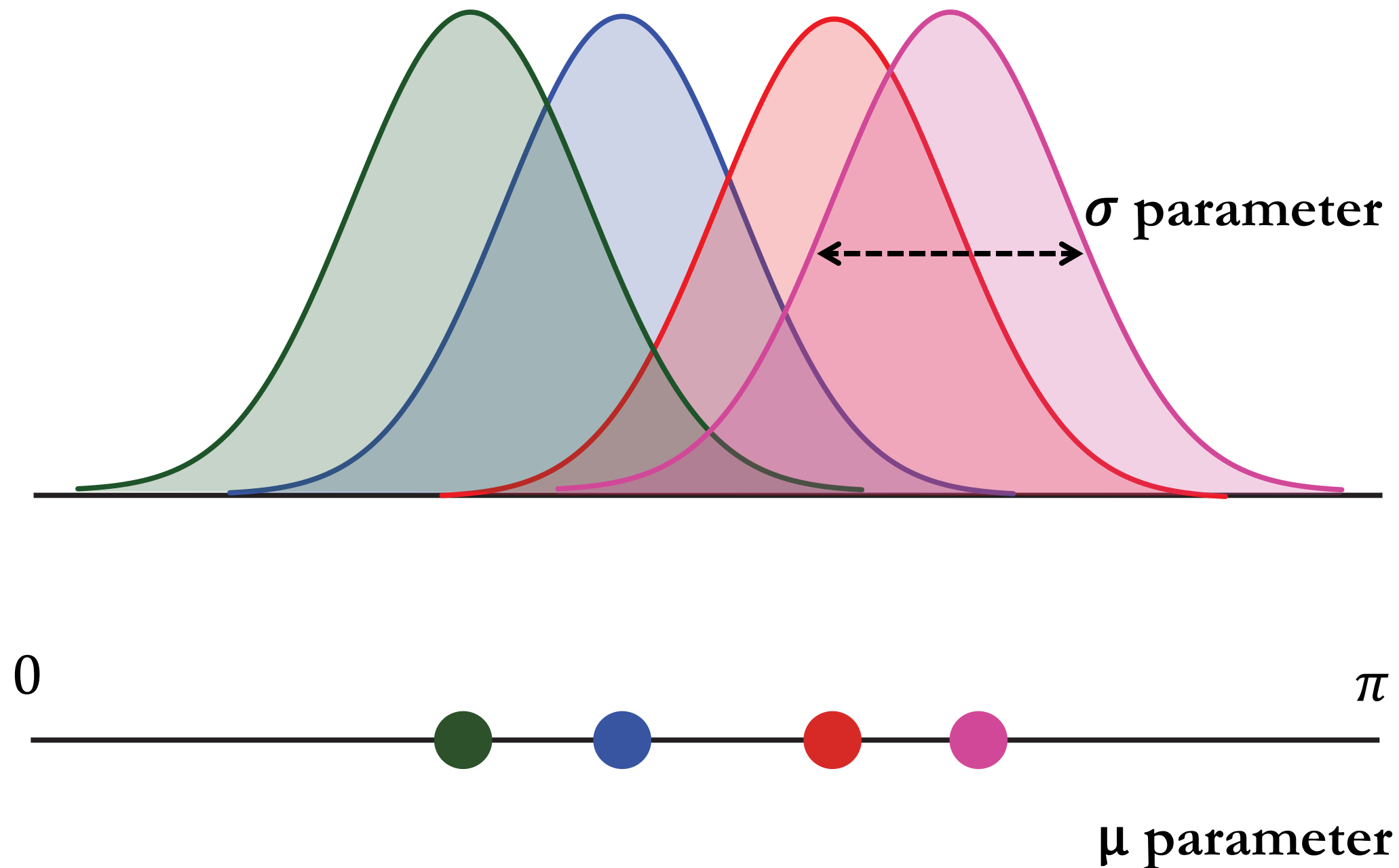
The shorter distance determines which pair is selected as being **more similar**.

# Our modeling approach



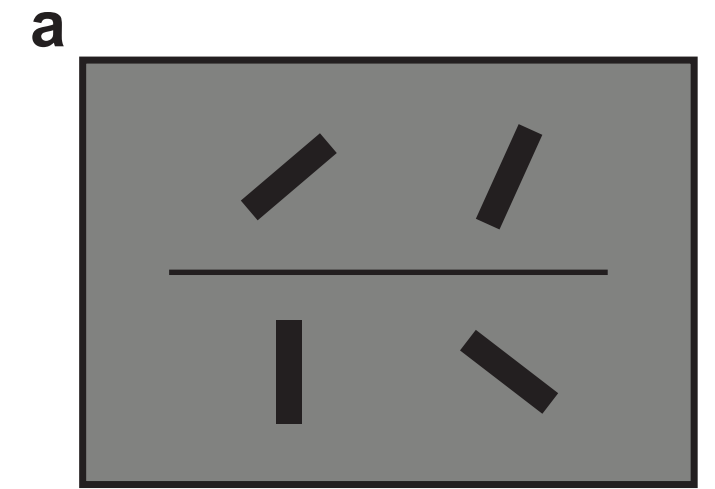
Repeat over a number of trials.

# Our modeling approach



The model infers the latent representations – the center of the distribution, and their common width – based on the response data.

# Similarity comparison



The orientation angle of the  
presented line stimulus

**A**

Physical

$\pi$   
 $\frac{3\pi}{4}$   
 $\frac{\pi}{2}$   
 $\frac{\pi}{4}$   
0

The mental representation of the line  
orientation

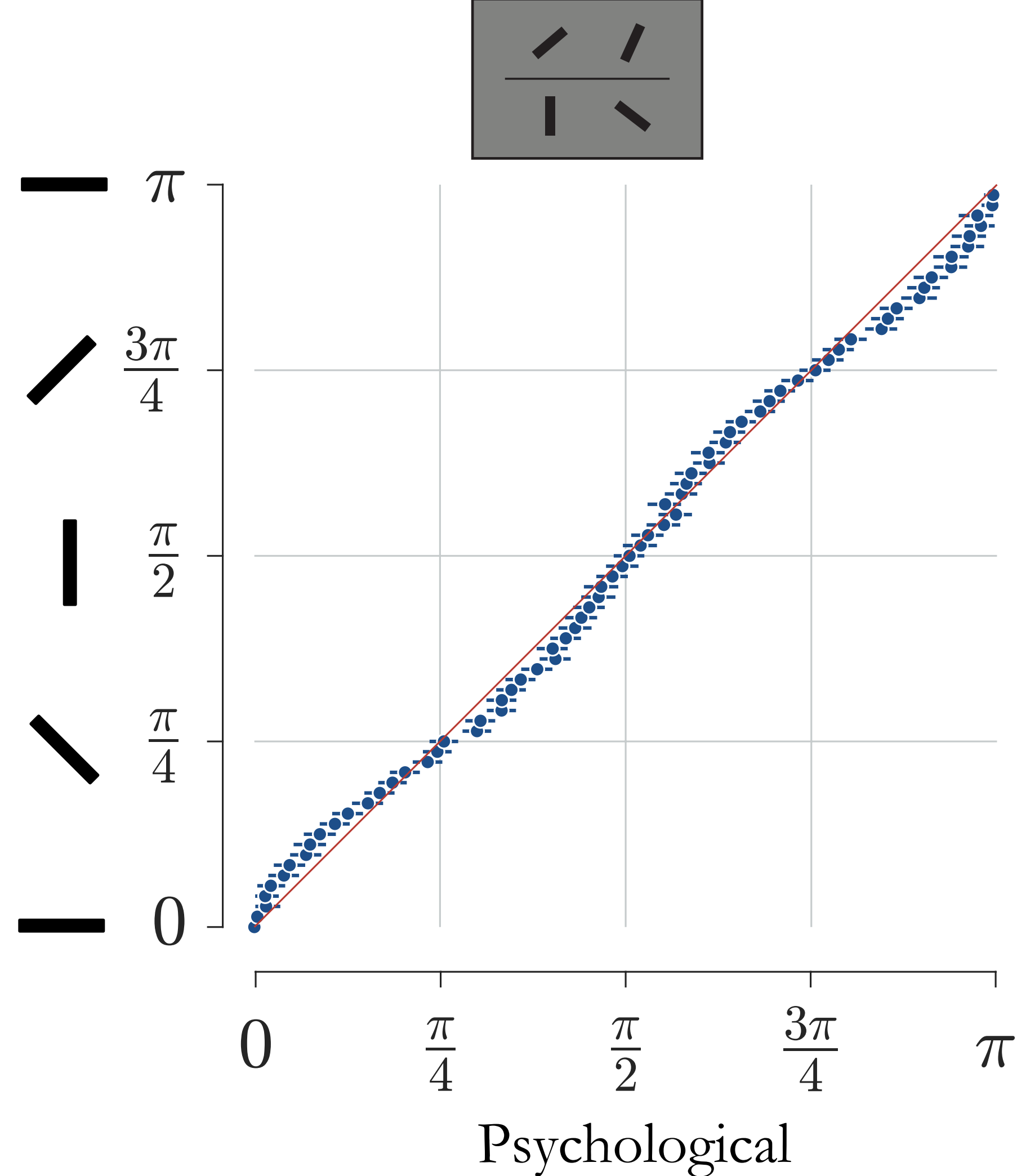
0  $\frac{\pi}{4}$   $\frac{\pi}{2}$   $\frac{3\pi}{4}$   $\pi$

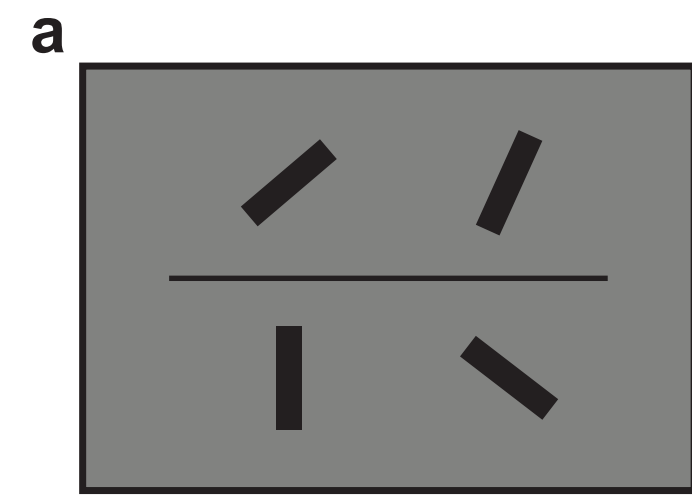
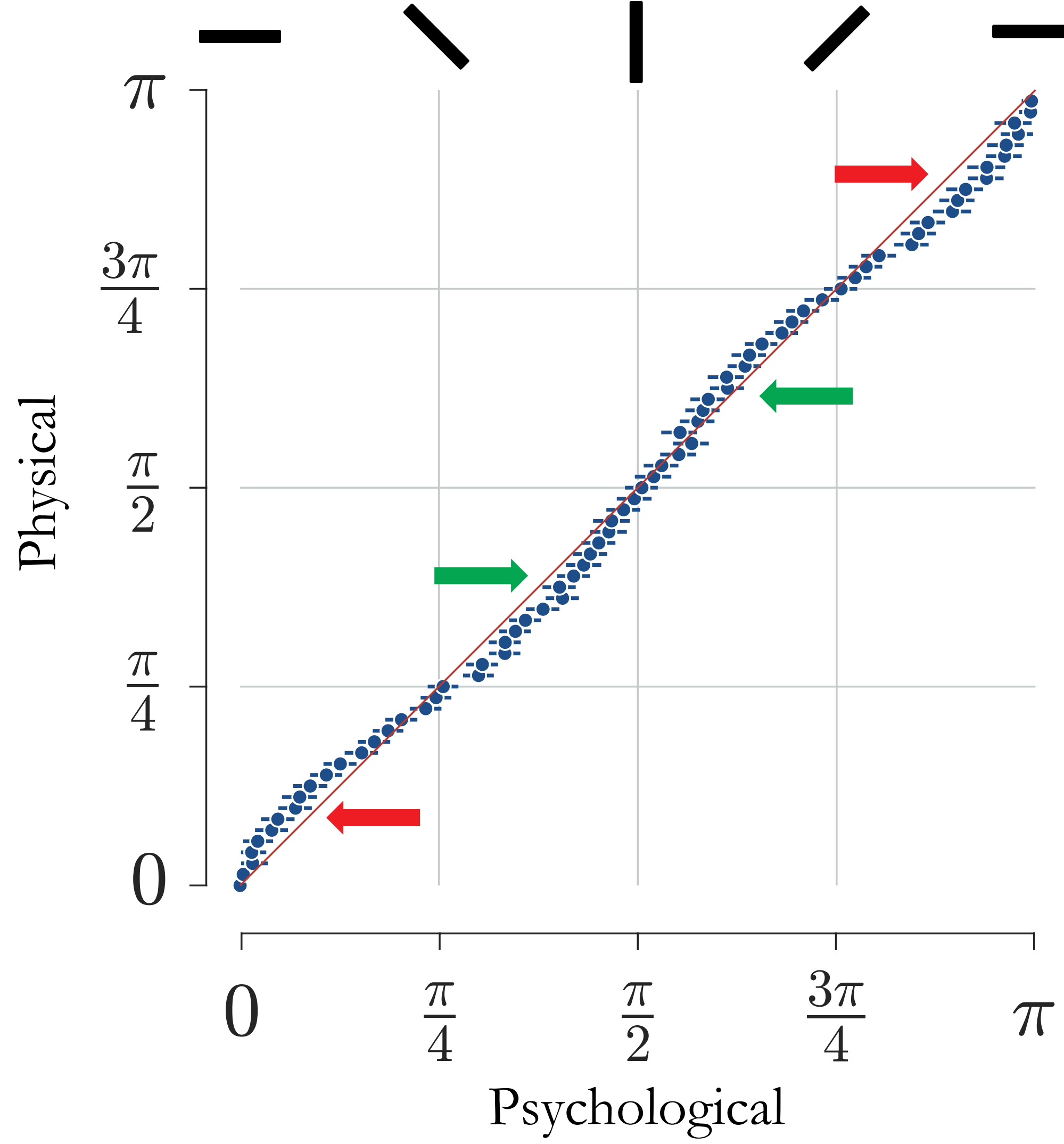
Psychological

# Similarity comparison

The representation **does not match the physical stimulus space** – it is not exactly a diagonal line.

Clear deviations where close to vertical lines appear more vertical, and close to horizontal lines appear more horizontal.



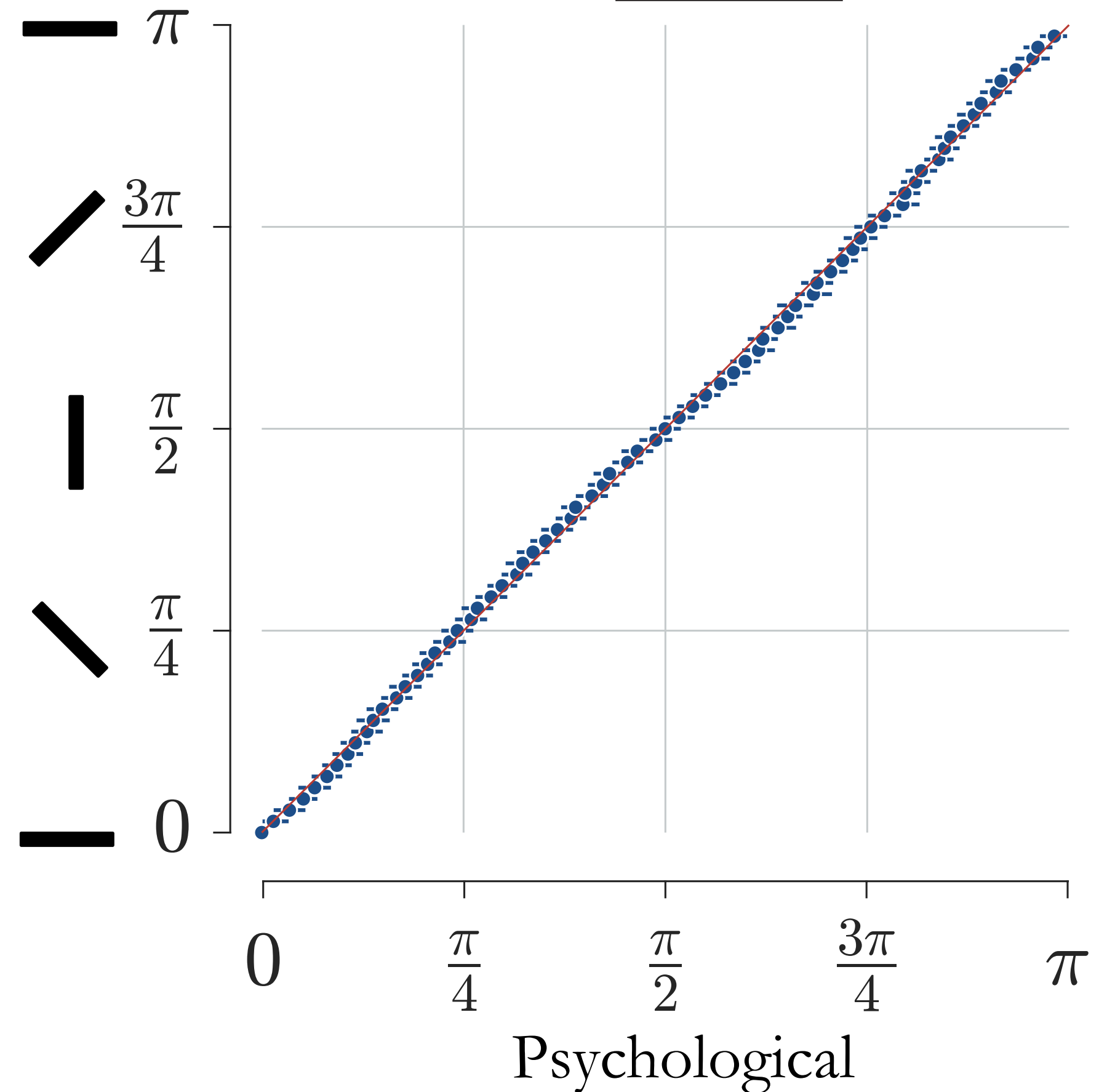




# Perceptual reproduction

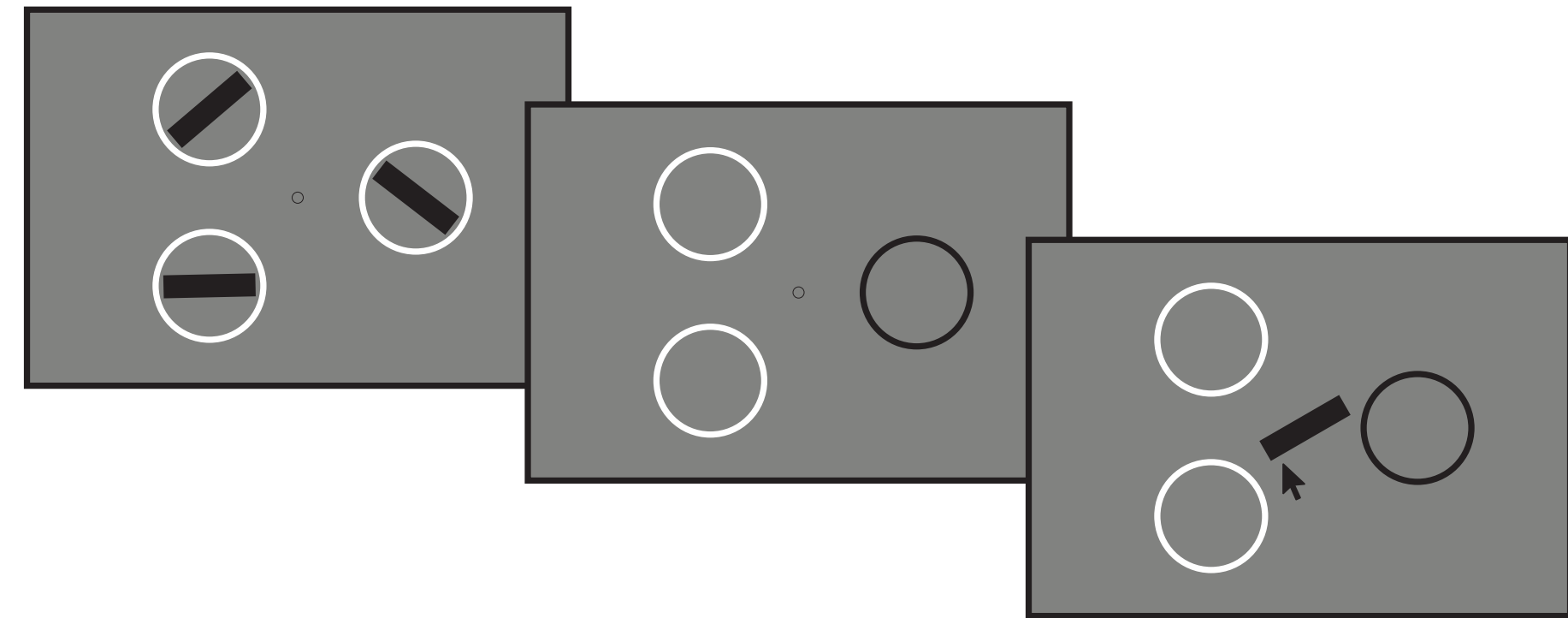
The representation is very close to the physical stimulus space, but there are slight deviations.

Not quite horizontal or not quite vertical lines are slightly biased away from the cardinal directions. This is the opposite to the similarity comparison.



# Memory reproduction

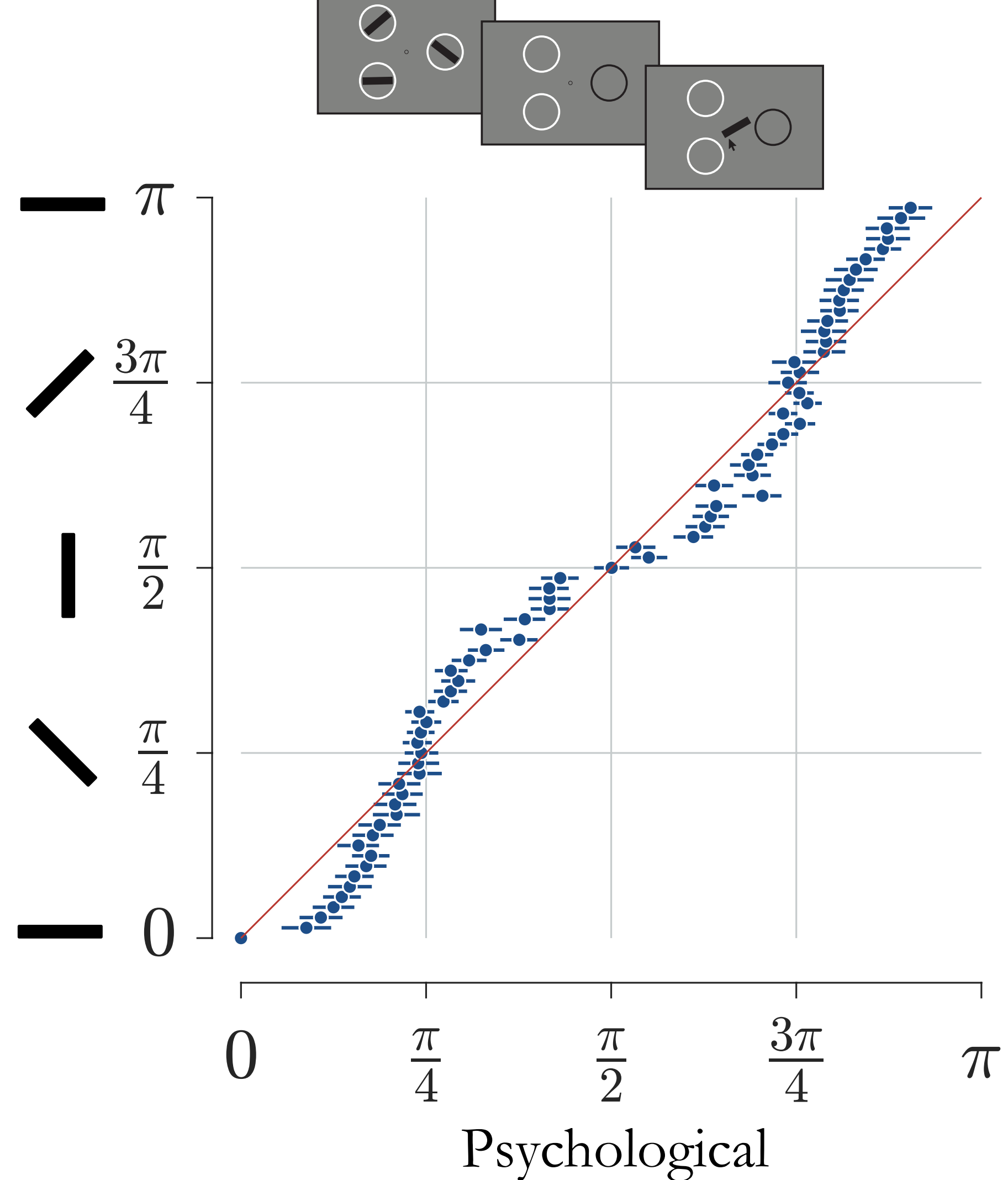
*NB.* The memory reproduction model includes a **swap error** process, where a sample is drawn from the latent representation of another item in the array.



# Memory reproduction

The representation is similar to the perceptual reproduction task but with larger deviations.

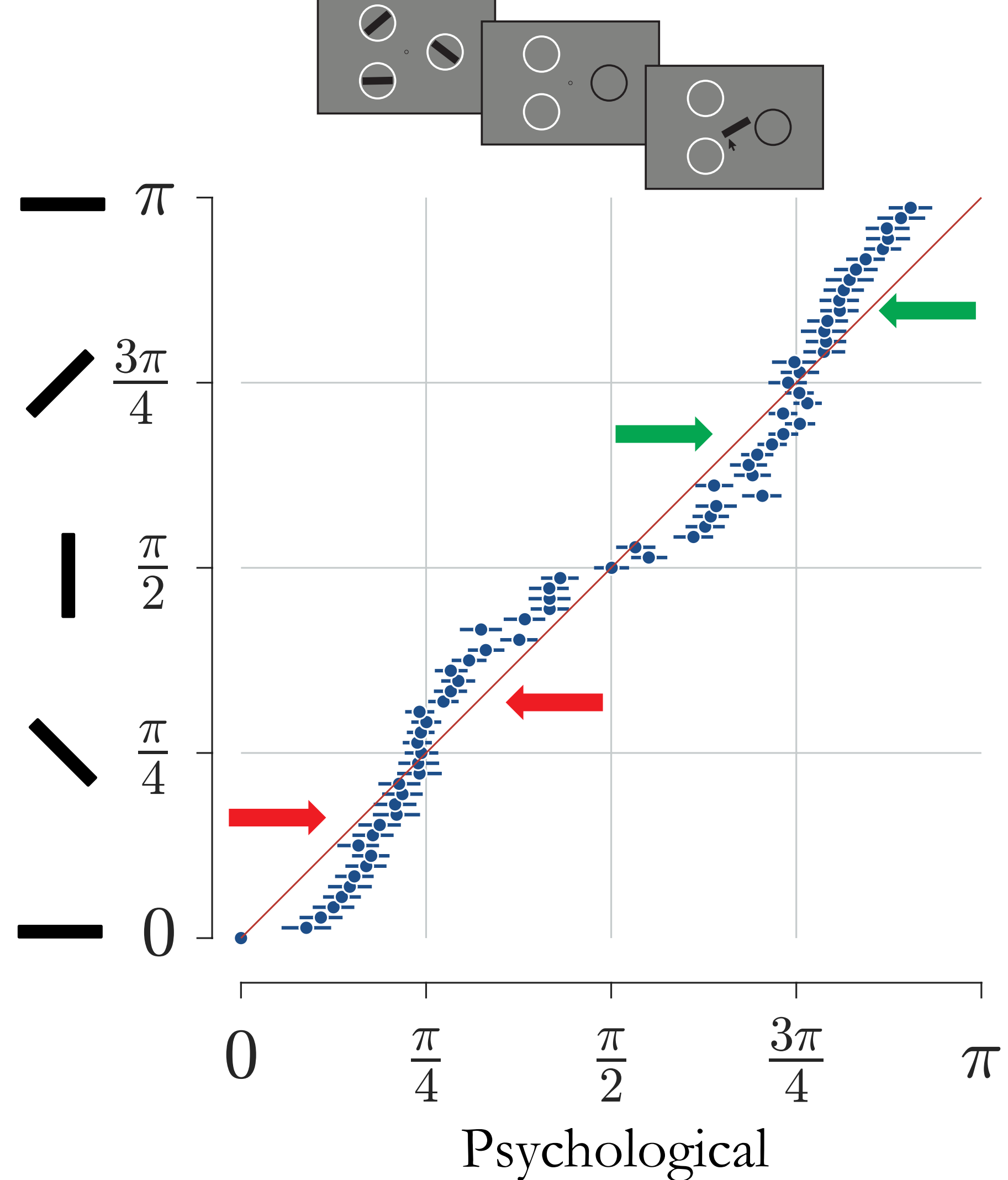
Lines are represented more towards the oblique directions than they actually are. This is the **opposite to similarity comparison.**



# Memory reproduction

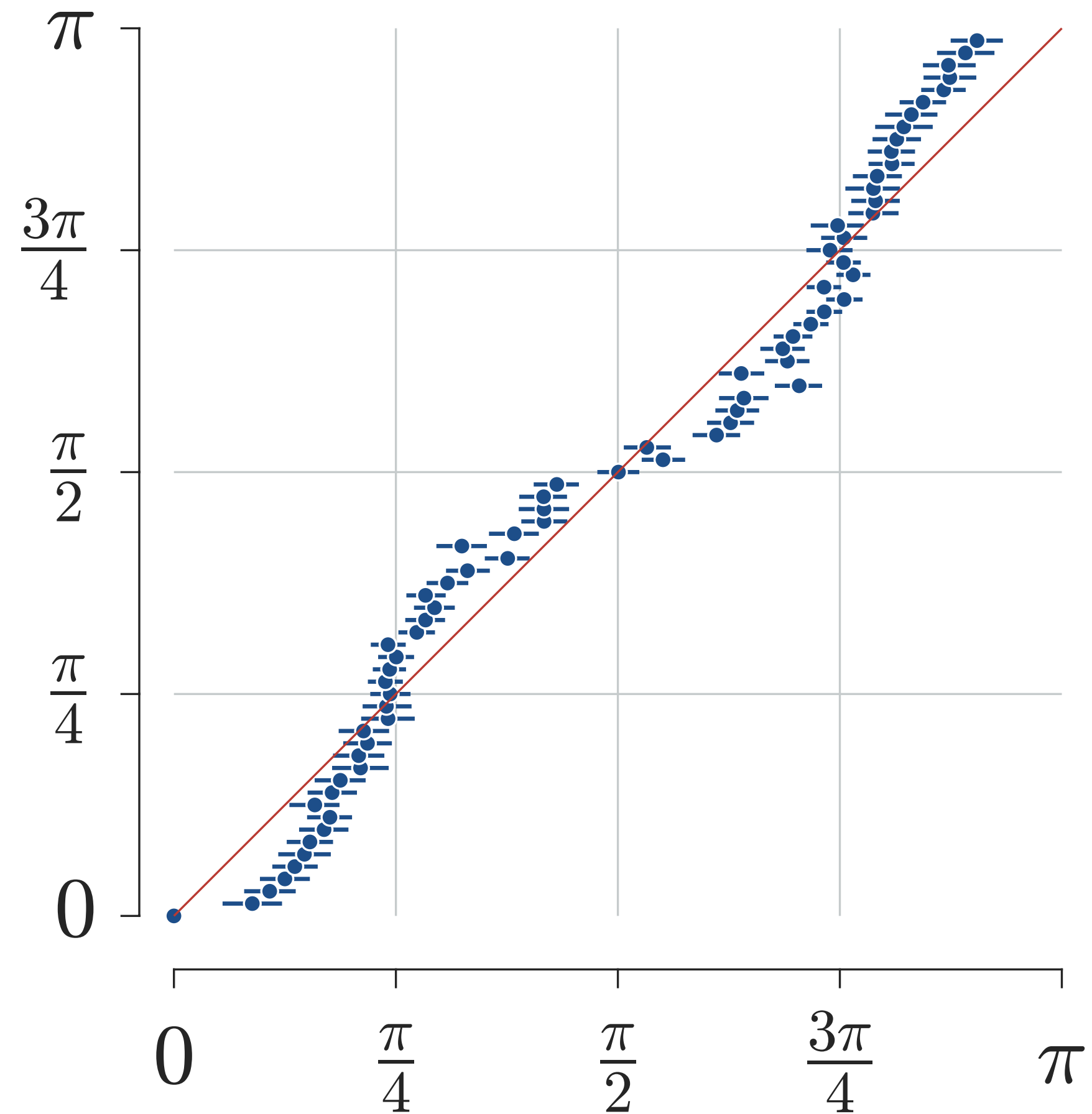
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# Conclusions

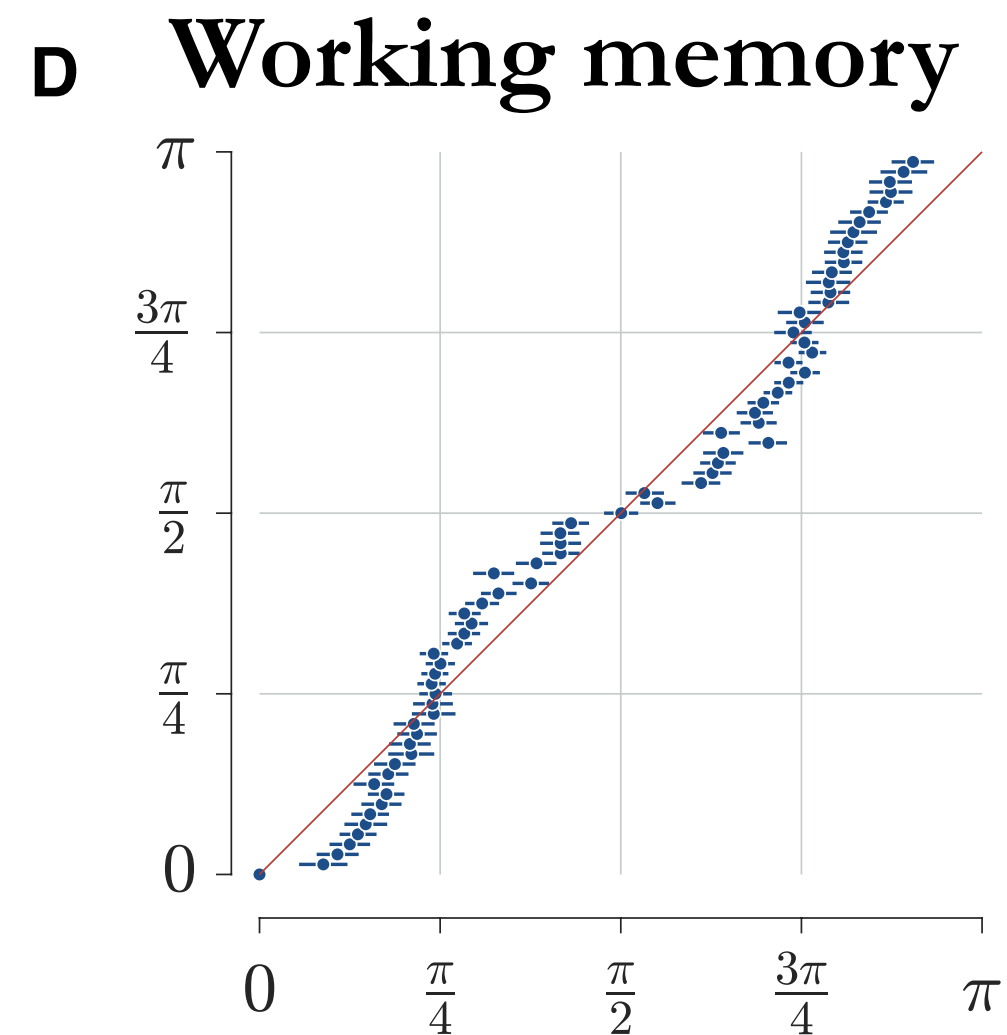
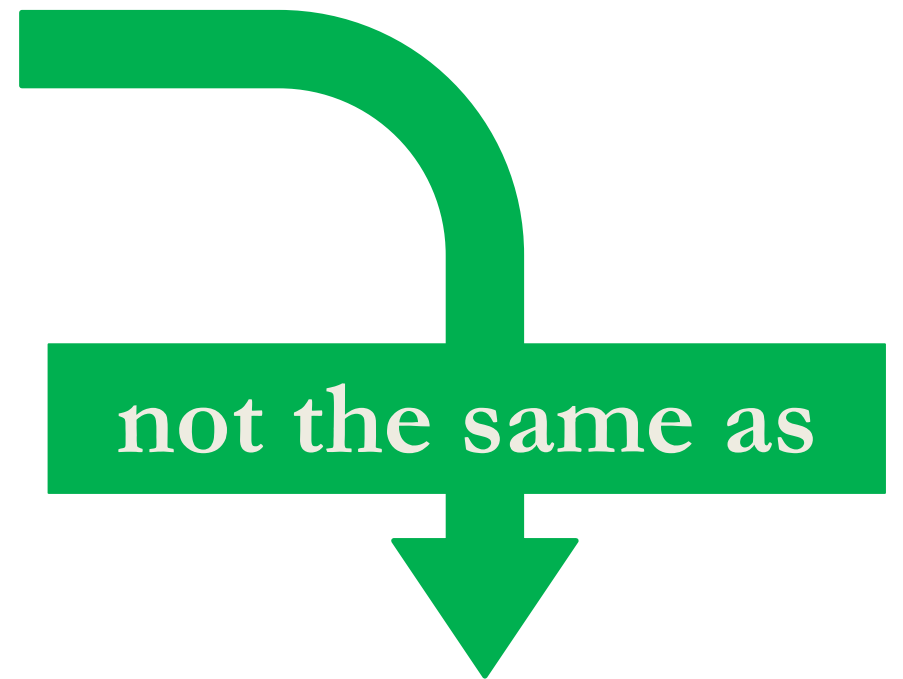
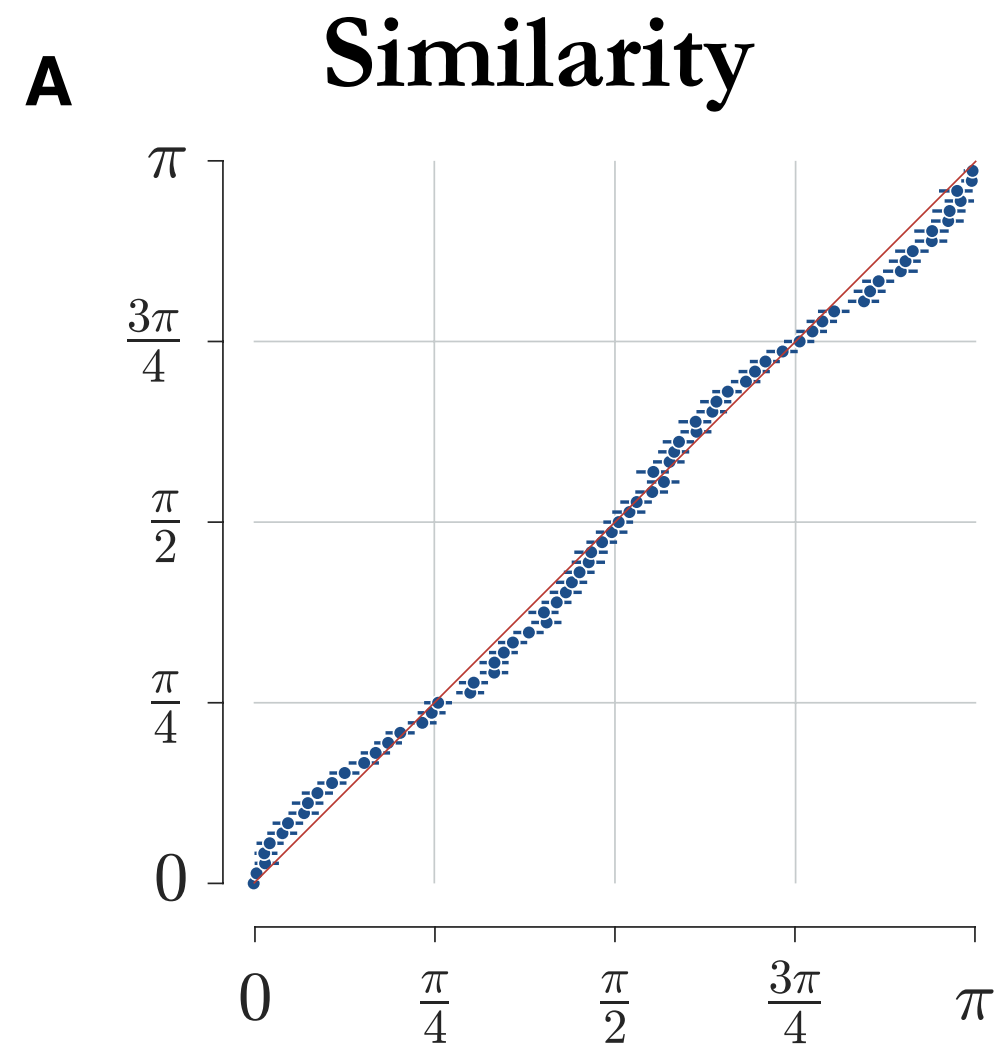
The cognitive representation for memory reproduction does not match the physical stimulus space. Therefore, models **should not assume the physical stimulus space** when modelling working memory performance.



# Conclusions

Similarity comparisons and both reproduction tasks **do not share the same cognitive representation.**

Therefore, psychological similarity cannot be assumed to be the basis for working memory.

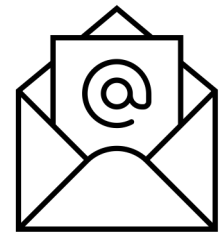


# Conclusions

Cognitive researchers ought not to assume the cognitive representation can be recovered using MDS of similarity-based judgments.

We advocate for our modeling approach that fits the cognitive representation **jointly** with the theorised mechanisms underlying the tasks.

# Thank you!



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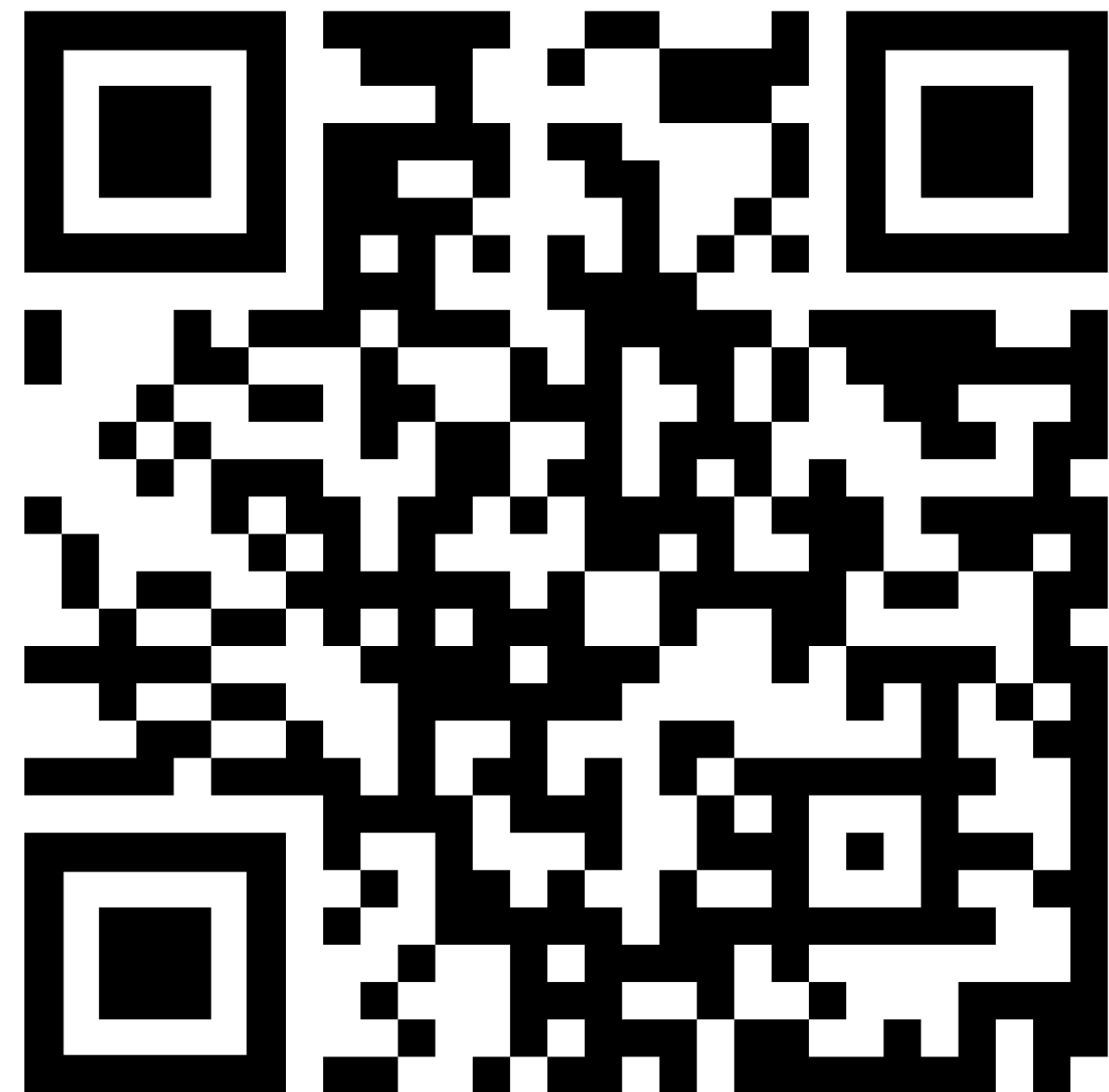
<https://palm-lab.github.io>



[@williamngiam.github.io](https://github.com/williamngiam)



Preprint with



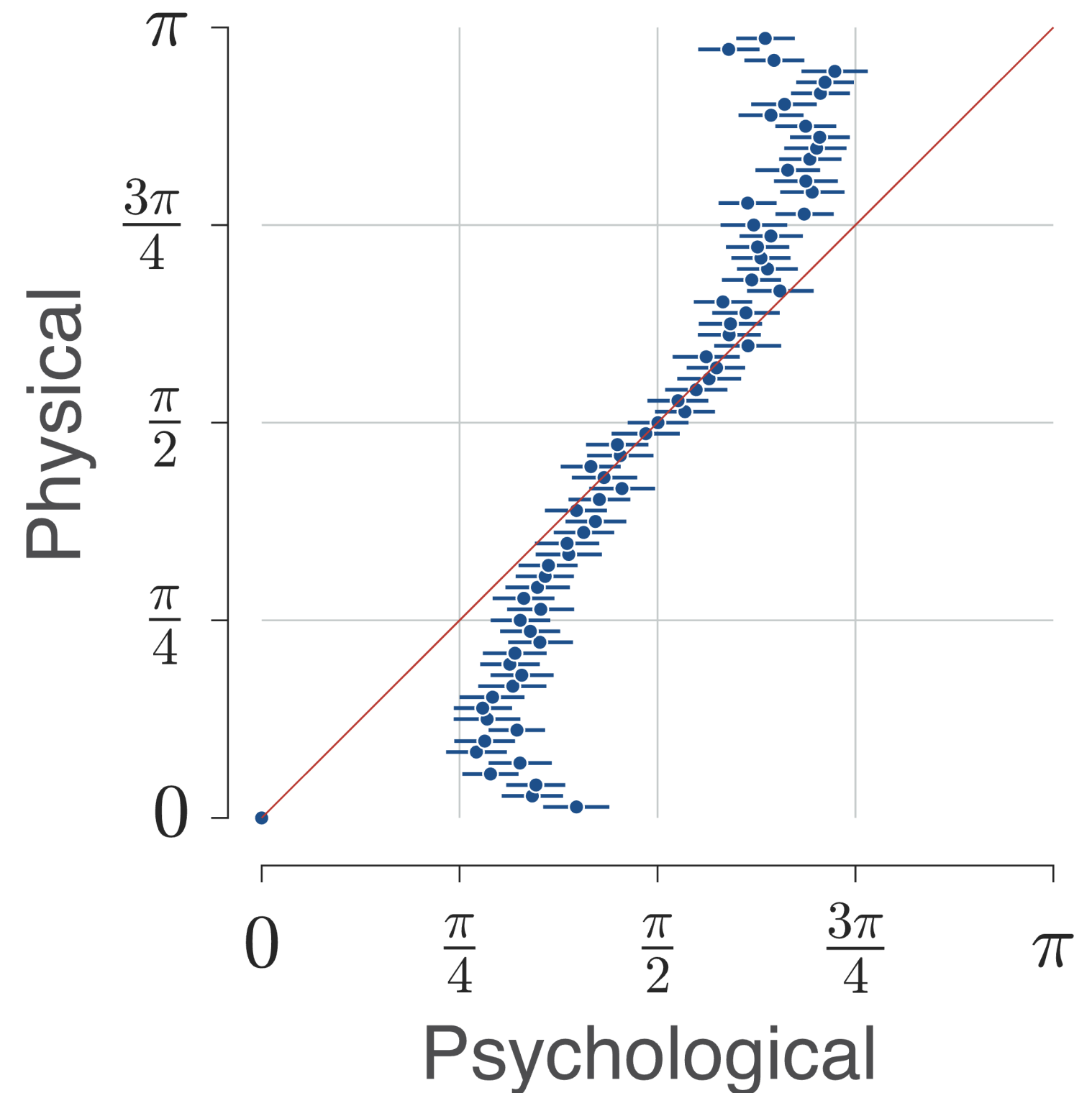


# Bonus slide #1 – better models improve fit

Refining the cognitive model by adding reasonable mechanisms improves the fit (and the recovered representation).

These are the results if **swap errors** are **not included** in the model.

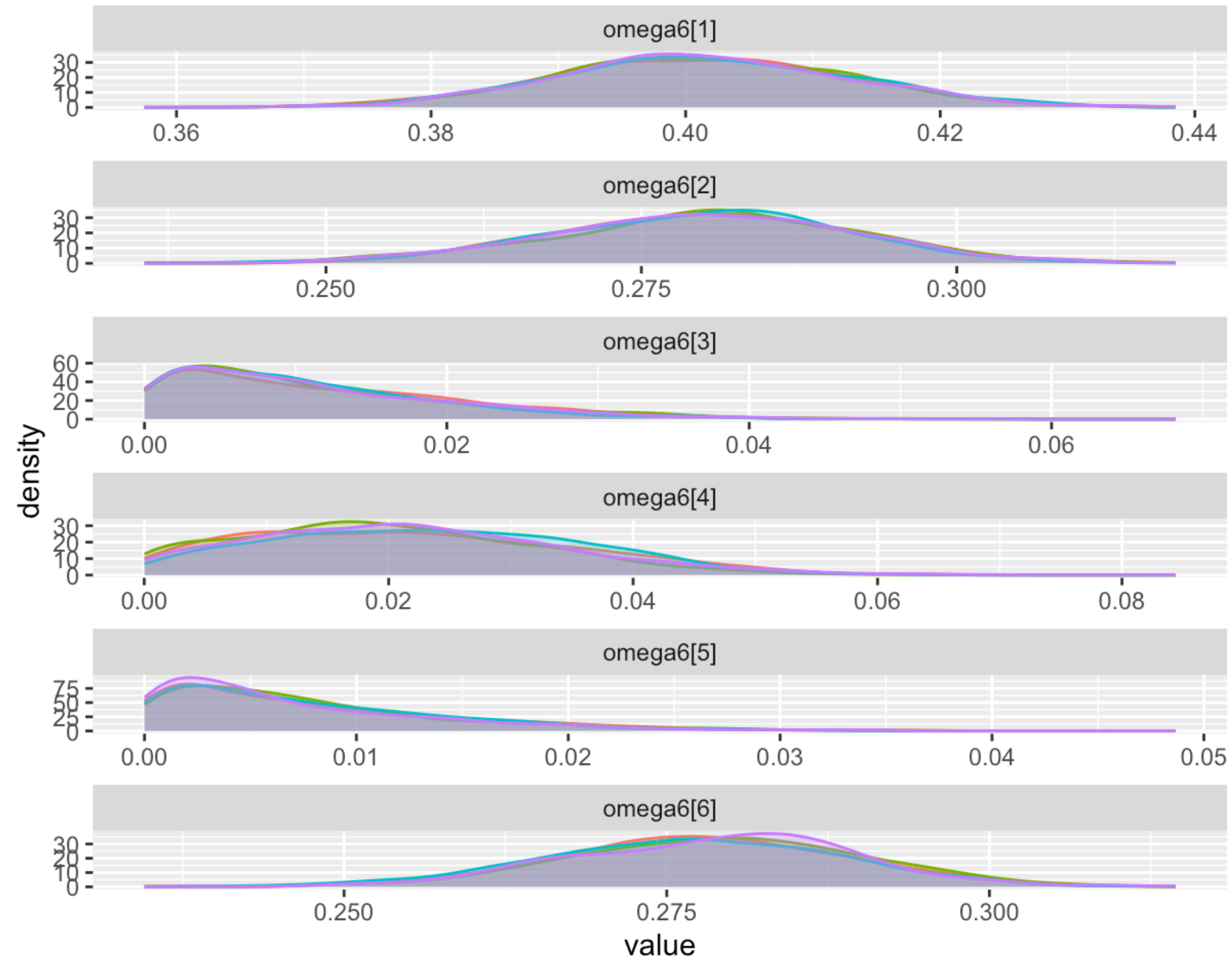
**c**



# Bonus slide #2 – swap error rate

The model includes the estimated standard deviation and swap error rate. The swap rates are shown in this figure.

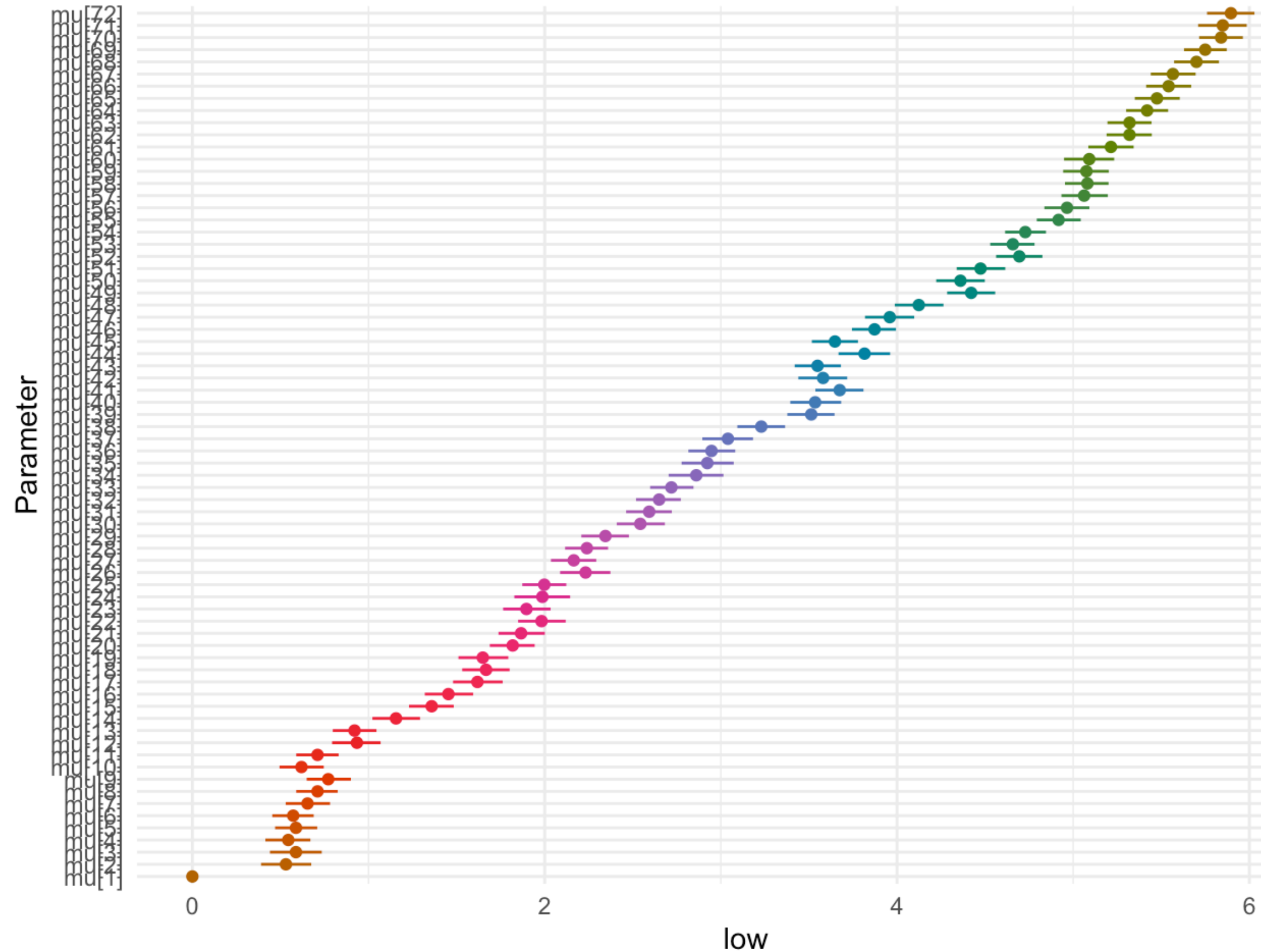
It appears swaps occur for the nearest neighbouring stimuli.



# Bonus slide #3 – latent representation of colour

We applied the same model to the memory reproduction task that used **colour stimuli**.

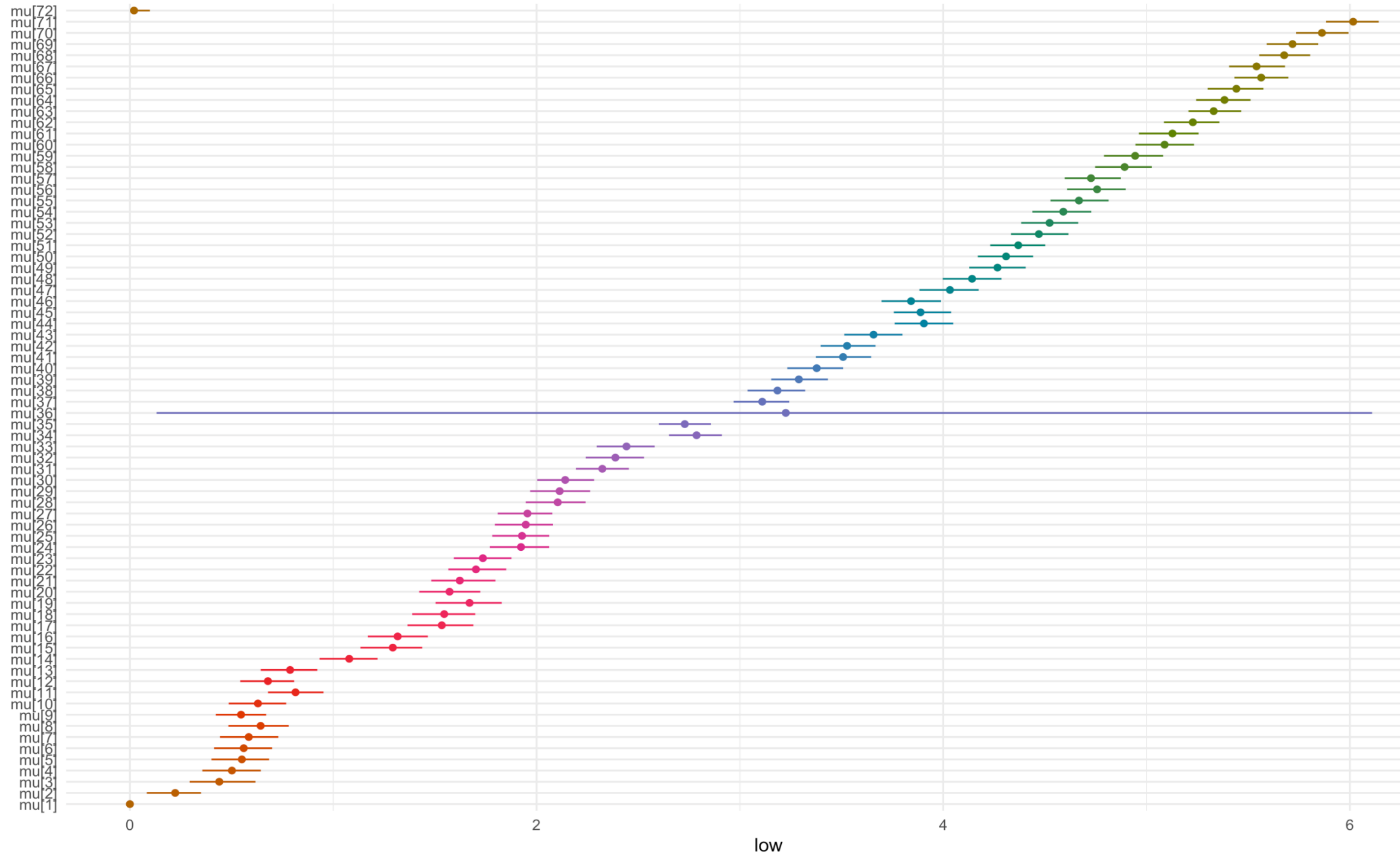
Each colour in the plot is what was shown in the experiment.



# Bonus slide #3 – latent representation of colour

We applied the same model to the similarity judgment task that used **colour stimuli**. (WIP)

Each colour in the plot is what was shown in the experiment.



# Bonus slide #4 – model selection?

There are a few theorised working memory models:

- Mixture of memory (von Mises) and guess (uniform)
- Mixture of memory and swap (von Mises, other shown item)
- Mixture of memory and swap and guess.

A current goal is to figure out how to rigorously conduct model comparison and **select** the most likely model across various datasets.