Intelligence in Animals and Machines

Seminar, Week 3

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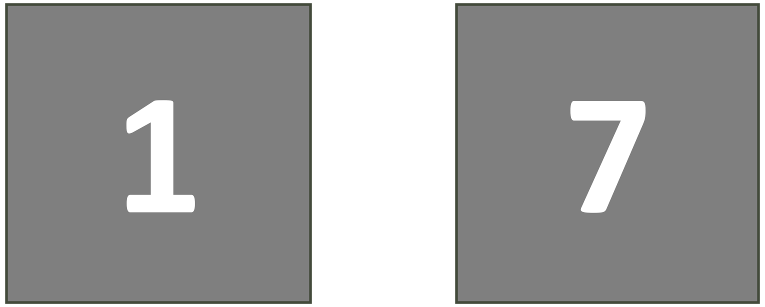
Magnitude estimation

- Ability discern size, density, etc
- “How much”
- A mid-level process related to perception

Numerical cognition

- Numerosity: an (approximate) sense of number; allows us to do maths
- Also allows us to represent e.g. time, cost, etc in numerical units
- Symbolic

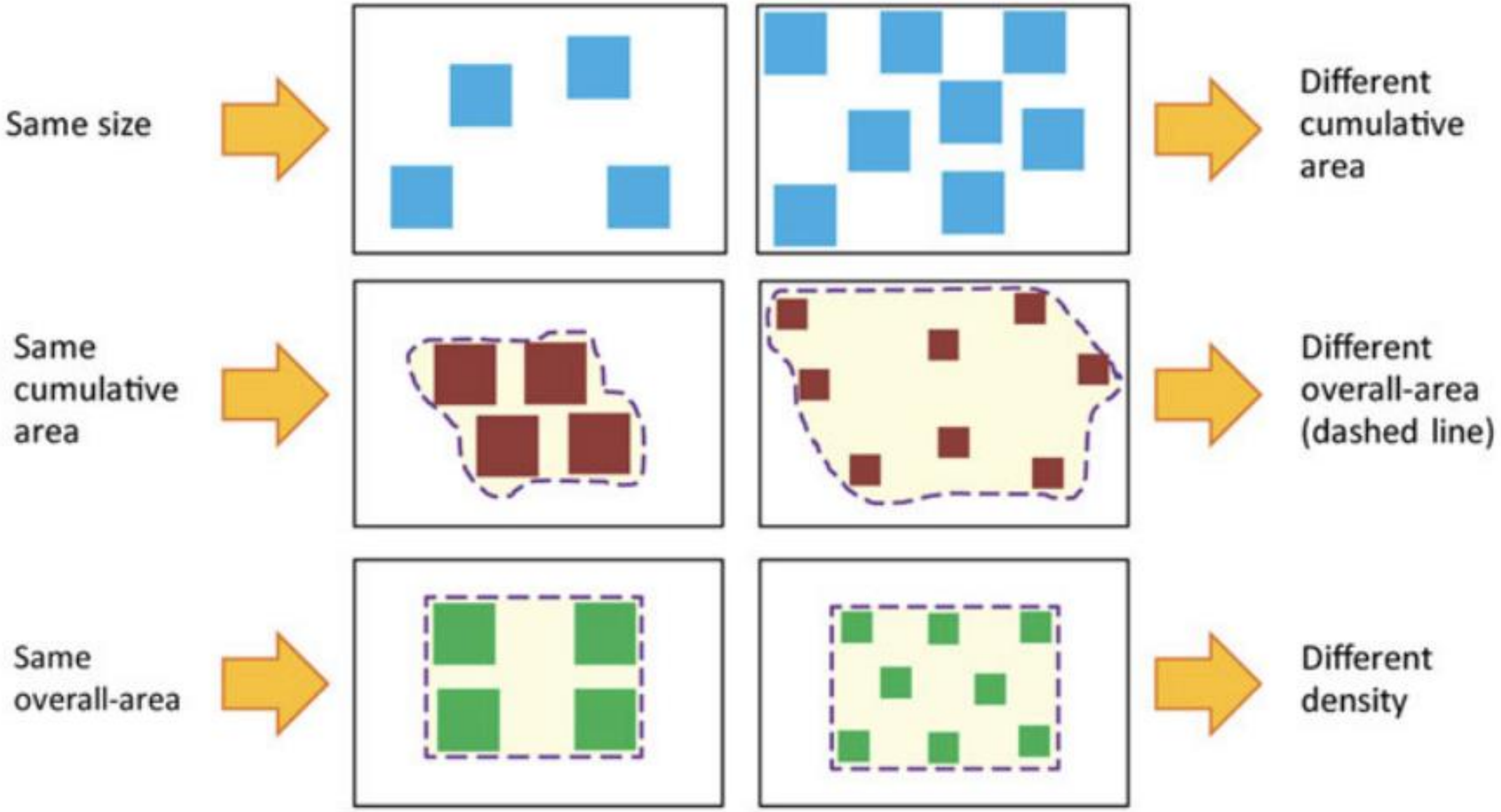
Studying numerosity is hard



Symbolic stimuli

Why will these often be a poor choice of stimulus for e.g. a dog?

Studying numerosity is hard



Leibovich and Henik (2013).

Can parrots do maths?

"Some studies show very sophisticated addition and subtraction abilities such as in the case of a chimpanzee and an African gray parrot that could both label the result of an addition sum using Arabic symbols or an English label, respectively, which would constitute exact numerical cognition" (Howard, 2019, Sci Adv)

Can parrots do maths?

ABSTRACT

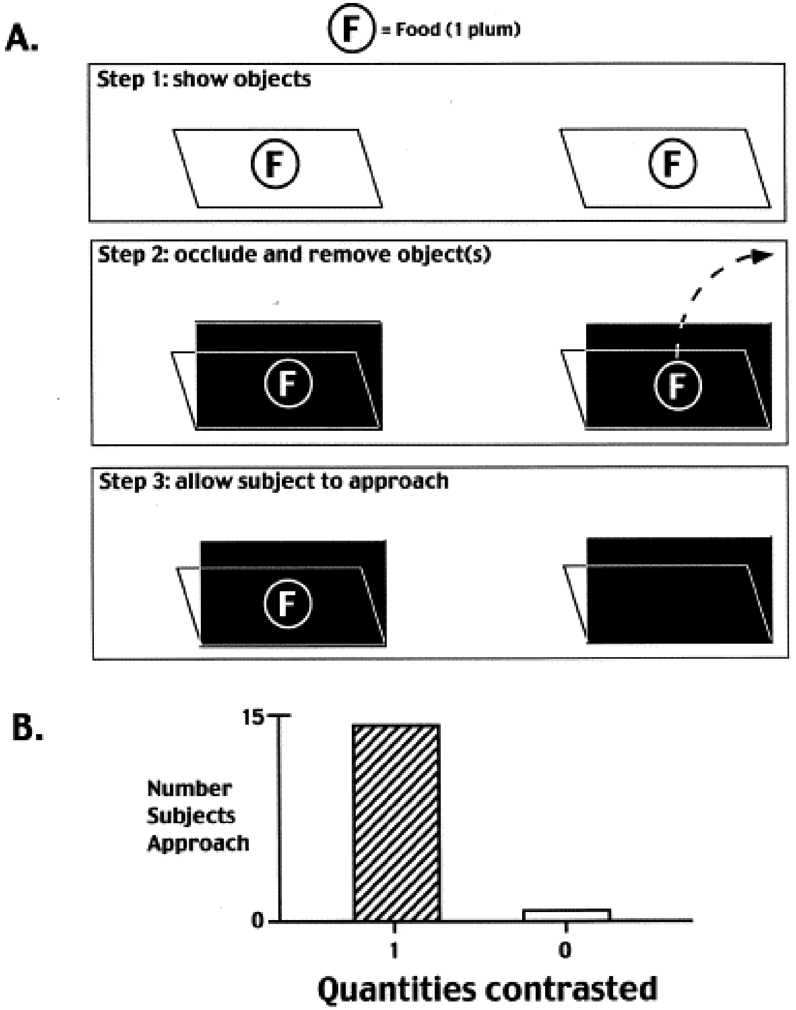
A Grey parrot (Psittacus erithacus), able to quantify 6 or fewer item sets (including heterogeneous subsets) by using English labels (I. M. Pepperberg, 1994), was tested on addition of quantities involving 0–6. He was, without explicit training, asked, "How many total X?" for 2 sequentially presented collections (e.g., of variously sized jelly beans or nuts) and required to answer with a vocal English number label. His accuracy suggested (a) that his addition abilities are comparable to those of nonhuman primates and young children, (b) some limits as to his correlation of "none" and the concept of zero, and (c) a possible counting-like strategy for the quantity 5.

Oscar Pfungst 1907

Can parrots do maths?

Can you think of a confound or a kill-joy explanation for this? Or not?

Subtraction in the rhesus monkey?



"Results show (Fig. 1B) that 14 out of 15 subjects (sign test: $P<0.001$) selected the platform with one plum over the platform with zero plums. This suggests that rhesus monkeys can represent the number of plums placed behind an occluder, and […] that rhesus monkeys can represent zero, as evidenced by the fact that they consistently pick one plum over no plums"

Sulkowski & Hauser (2001). Cognition

What’s going on?

Discussion

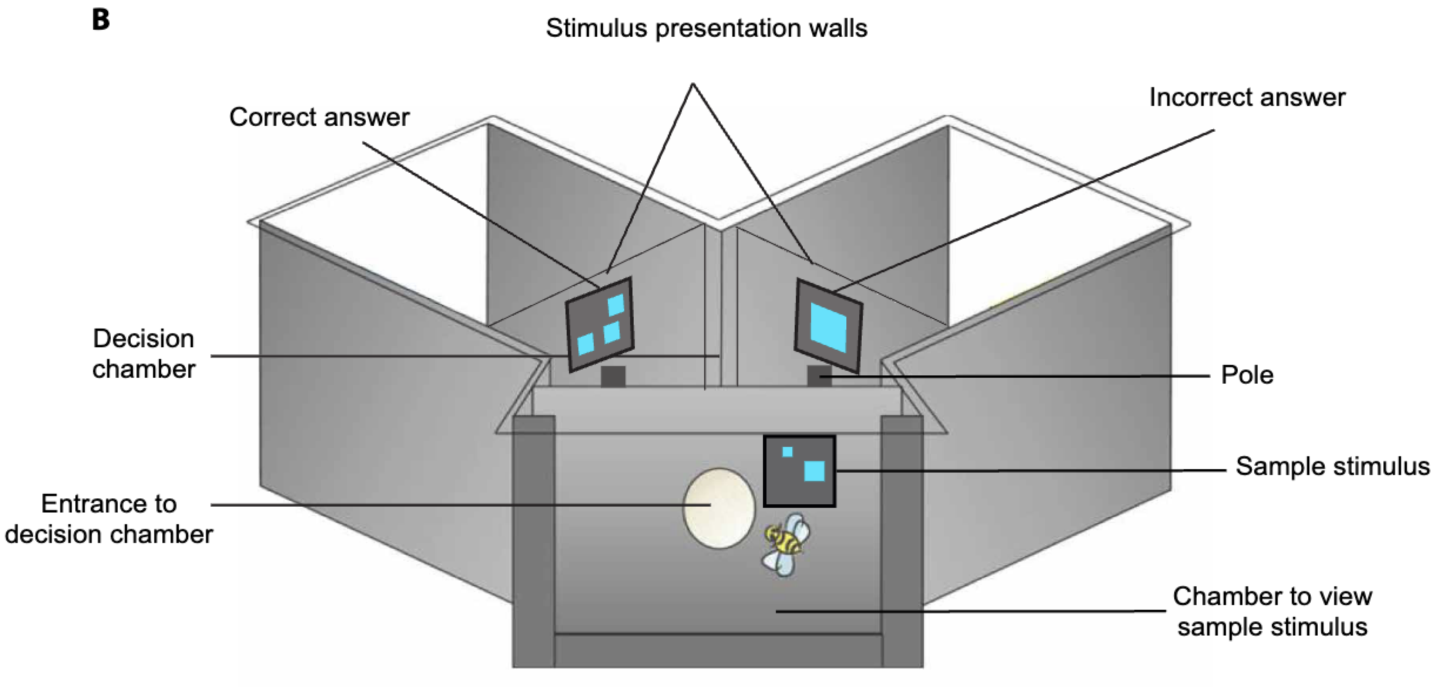
SCIENCE ADVANCES | RESEARCH ARTICLE

COGNITIVE NEUROSCIENCE

Numerical cognition in honeybees enables addition and subtraction

Scarlett R. Howard[1], Aurore Avarguès-Weber[2], Jair E. Garcia[1], Andrew D. Greentree[3], Adrian G. Dyer[1,4]*

Method



Blue = add one element

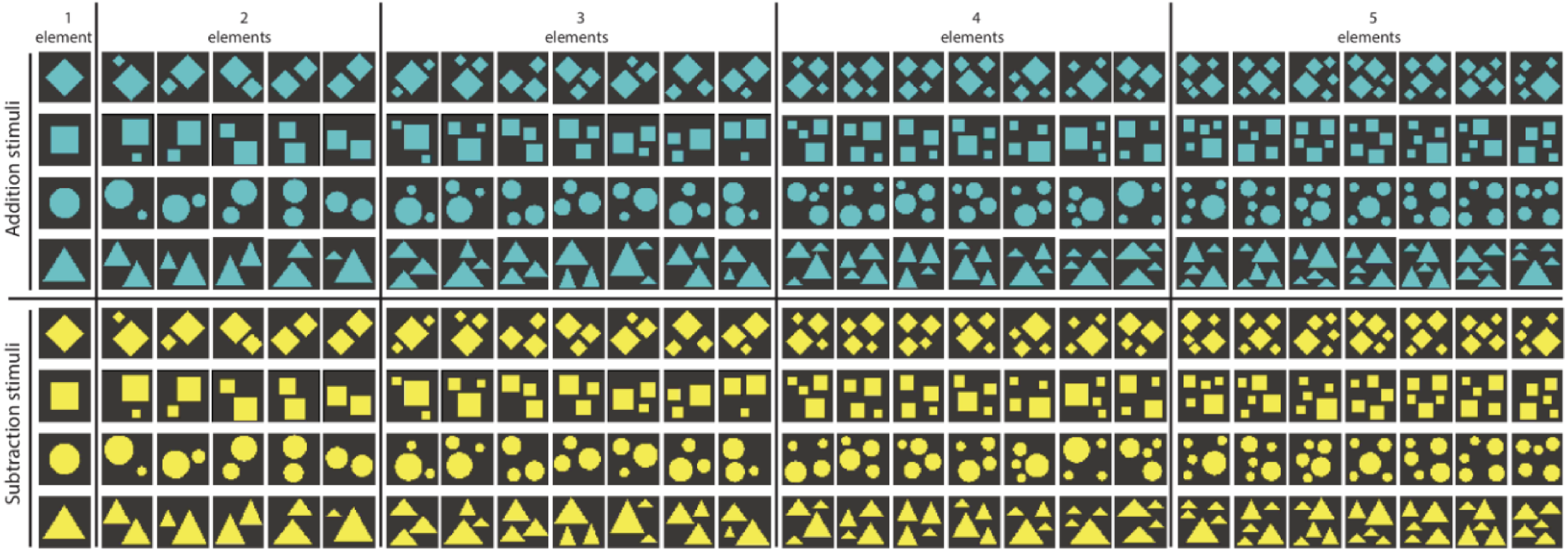
"A 10-μl drop of either a 50% sucrose solution (correct choice) or a 60 mM quinine solution (incorrect choice) was used as rewarding and punishing outcomes"

Method

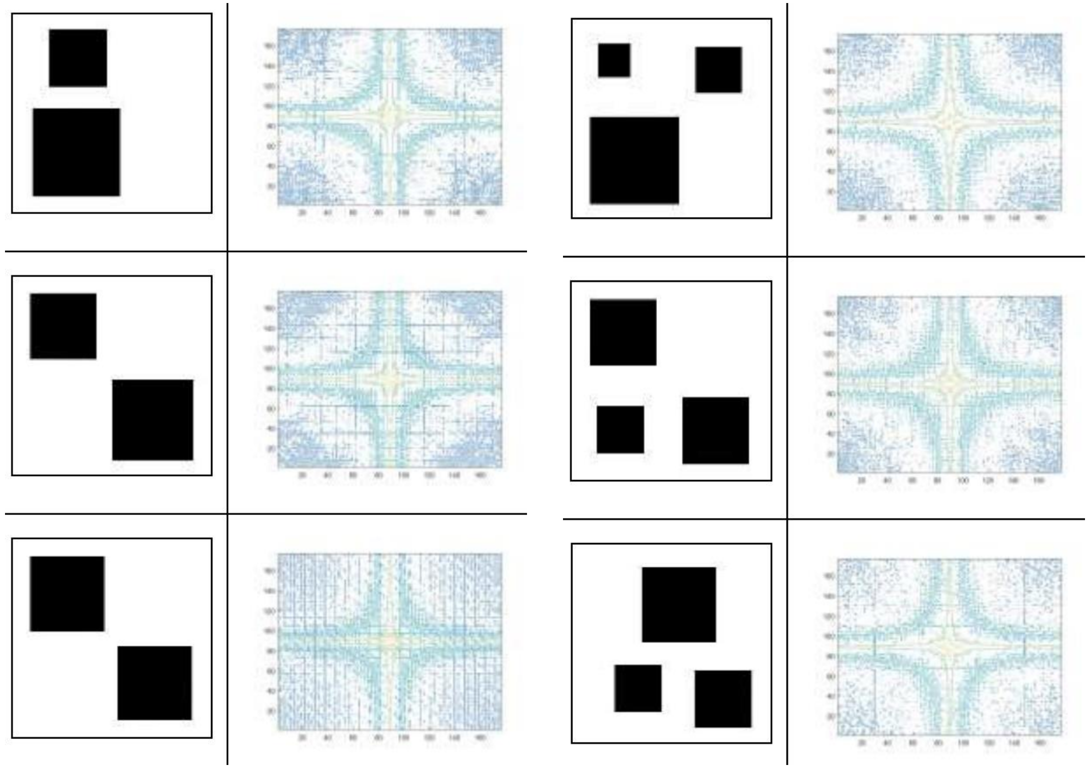
- Training:
  - 100 trials, addition & subtraction intermixed
  - Reward = 10-ul of 50% sucrose solution
  - Punishment: 10-ul of a 60 mM quinine solution
  - Solutions were held at the landing poles by each stimulus (also during testing? Not clear)
  - Random incorrect answer (not “3”)

- Test:
  - 2 x addition trials, 2 x subtraction trials (all including “3”)

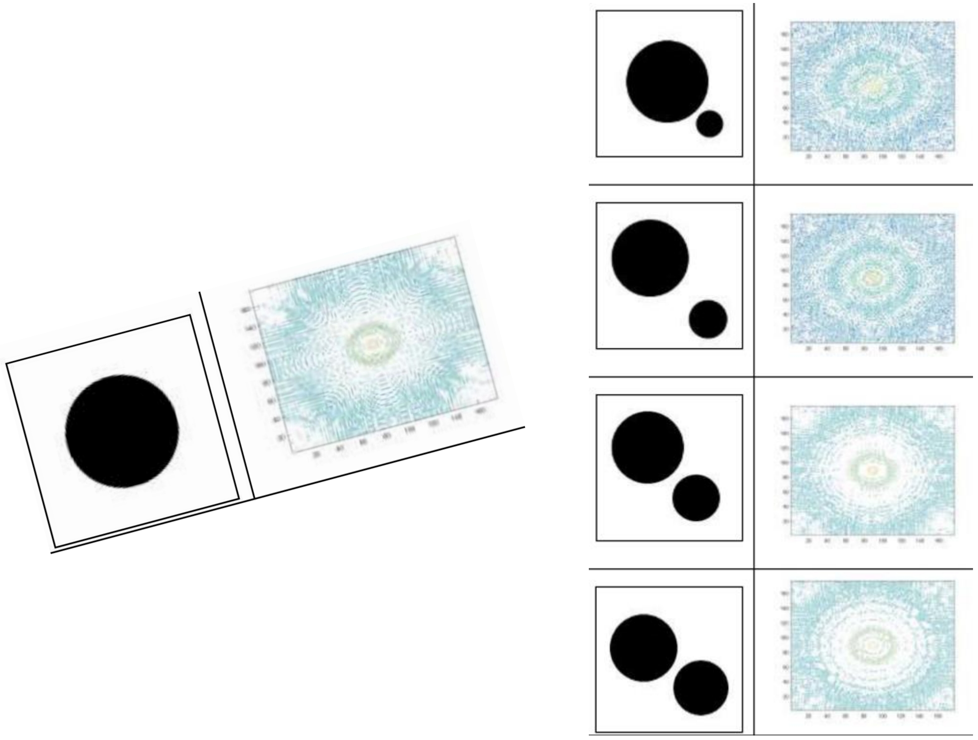
Method


1 element
2 elements
3 elements
4 elements
5 elements
Addition stimuli
Subtraction stimuli

Method



Spatial frequency (light-dark alternations) representations of the stimuli



Howard et al (2018), Sci Adv, Supplementary Materials

Analysis: statistical model

Effect of training:

Accuracy ~ 1 + trial number + (1 | bee)

Response is correct (training data) = group mean accuracy + effect of learning + allow each bee to have its own mean accuracy

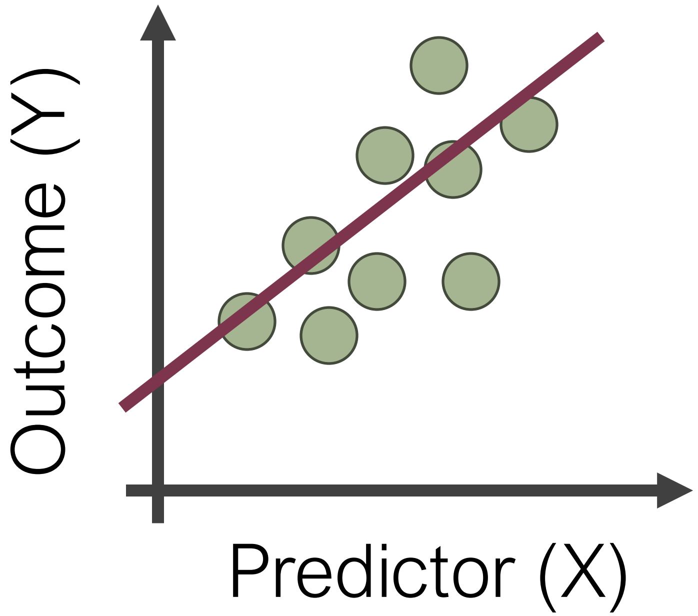
Ability to learn:

Accuracy ~ 1 + (1 | bee)

Response is correct (test data) = group mean accuracy + allow each bee to have its own mean accuracy

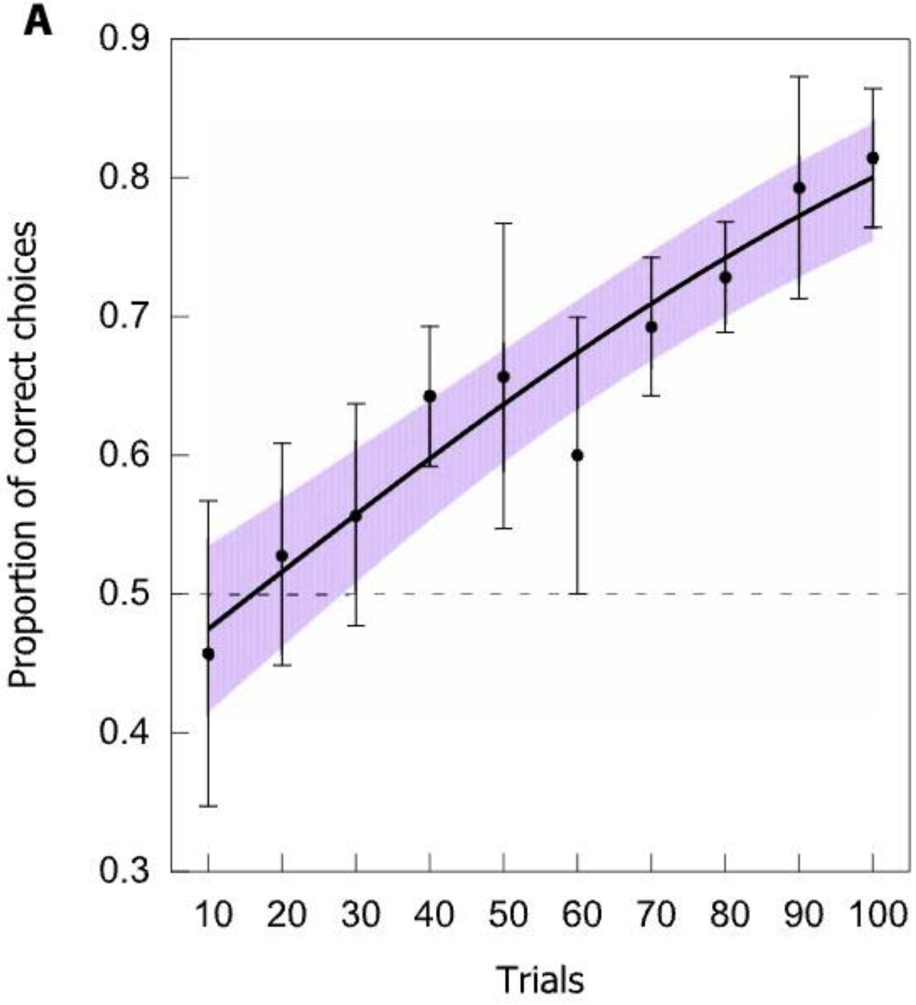
Analysis: statistical model

Regression: outcome = intercept + (b x predictor)

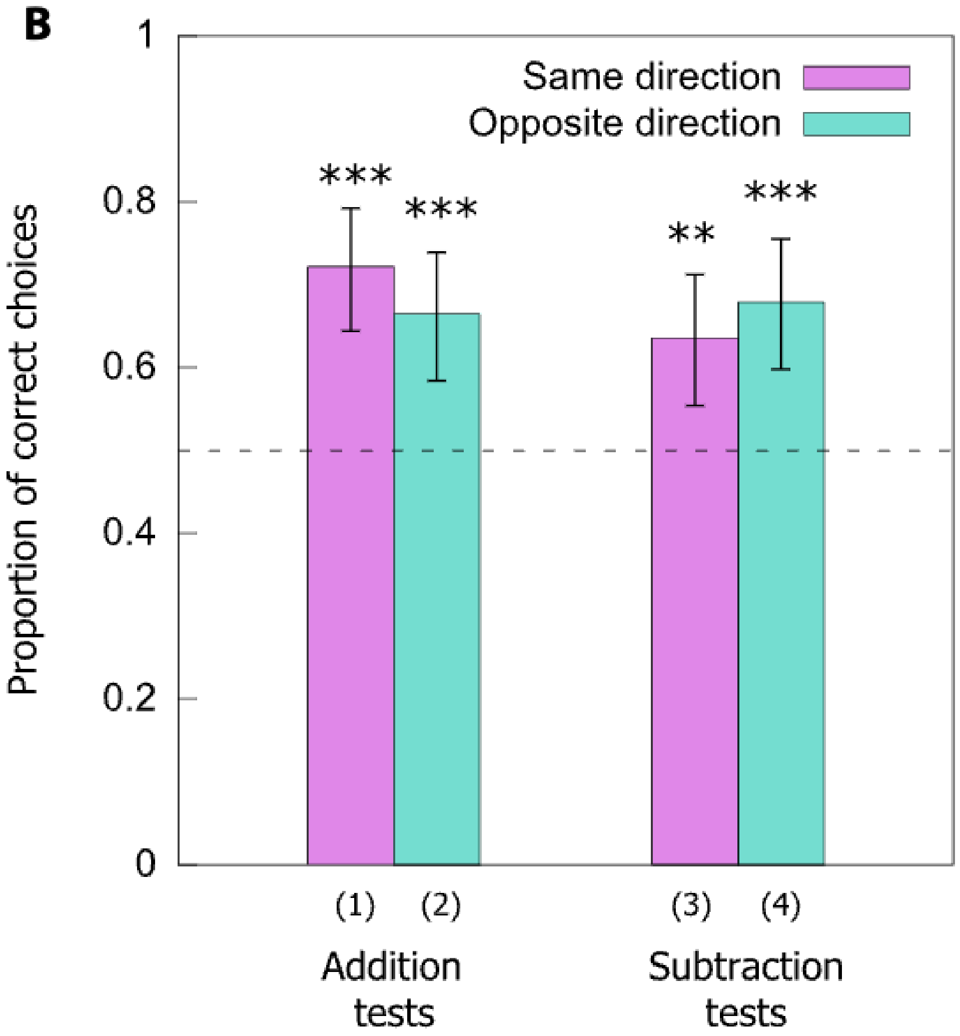


You can think of LMMs as the combination of lots of regression lines, one for each bee (ish)

Results


A
0.9
0.8
0.7
0.6
0.5
0.4
0.3
Proportion of correct choices
10 20 30 40 50 60 70 80 90 100
Trials

Results



Example:

Same direction: 3 + 1 = 4 OR 5

Opposite direction: 3 + 1 = 2 OR 4

What does this control for?

Discussion

“Arithmetic operations such as addition and subtraction problems are known to involve complex cognitive processes as they require two levels of information processing. The first is the **representation of numerical attributes**, and the second is the **mental manipulation** of those representations in **working memory**”

Discussion

"While the specific task of addition/subtraction may not be directly apparent in the honeybee's natural environment, the skills and cognitive plasticity required for performing the arithmetic task are likely to be ecologically advantageous. For example, the ability of bees to acquire and manipulate learned information to make decisions using multiple memory phases (23) is **useful in foraging to remember which flower traits (e.g., color, shape, and size) may provide essential resources and which flower traits may not** (35)."

Discussion

"Combined with the results from our current study, we propose that language and prior advanced numerical understanding are not a prerequisite necessary for the ability to calculate addition and subtraction solutions."

Discussion (examples)

- To conclude a non-human animal can add & subtract, what processes would you want to have demonstrated?
- What would it mean for a bee to be able to do maths?
- Do you need numeric representations, language or working memory to do this task?
- How do you distinguish between numerosity discrimination & arithmetic?

Another way?

PROCEEDINGS B

royalsocietypublishing.org/journal/rspb

Research

Check for updates

Cite this article: MaBouDi HD *et al*. 2021 Non-numerical strategies used by bees to solve numerical cognition tasks. *Proc. R. Soc. B* **288**: 20202711.
https://doi.org/10.1098/rspb.2020.2711

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Non-numerical strategies used by bees to solve numerical cognition tasks

HaDi MaBouDi[1,†], Andrew B. Barron[1,2,†], Sun Li[3], Maria Honkanen[4], Olli J. Loukola[4], Fei Peng[3], Wenfeng Li[5], James A. R. Marshall[1], Alex Cope[1], Eleni Vasilaki[1] and Cwyn Solvi[2,6]

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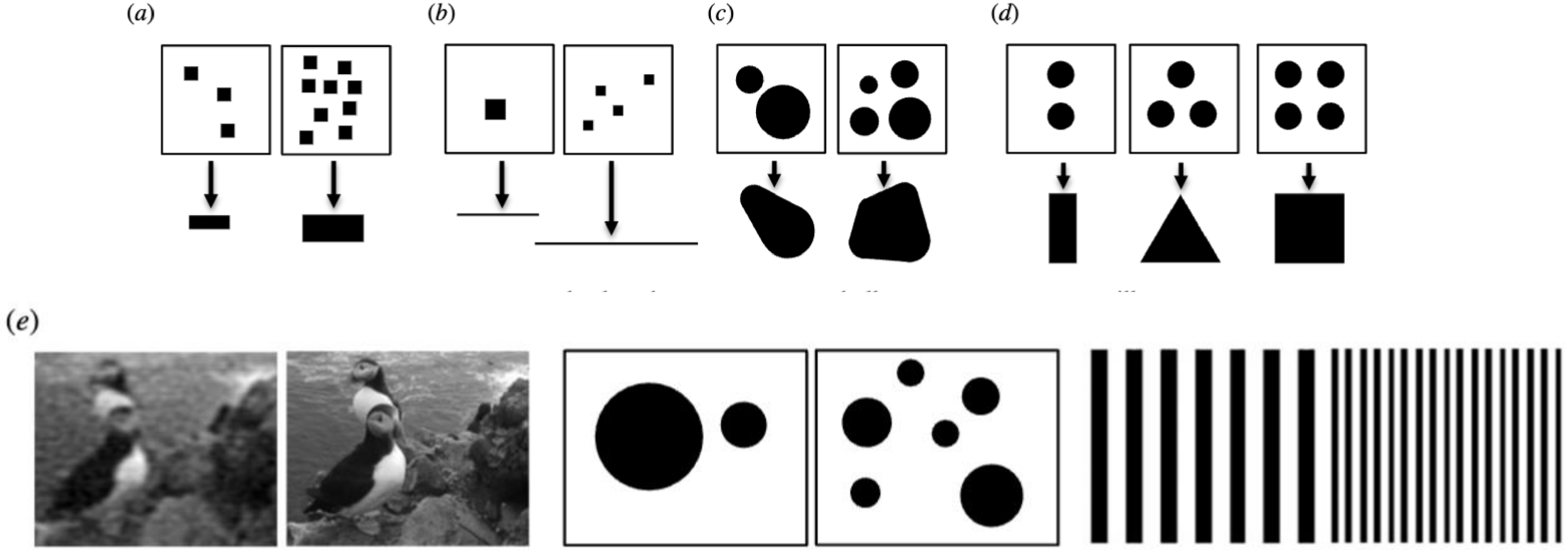
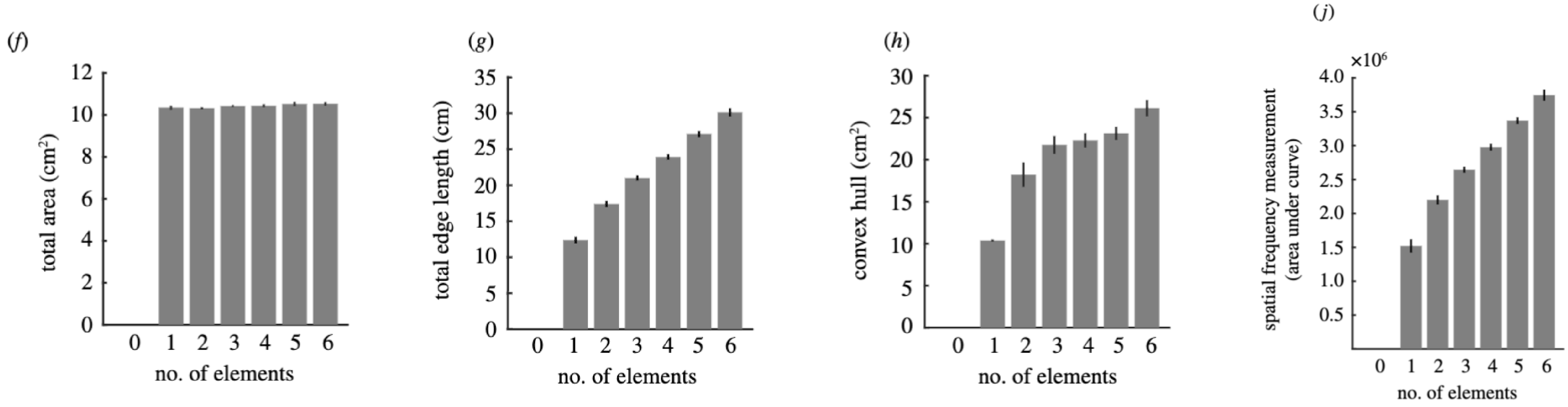
Another way?



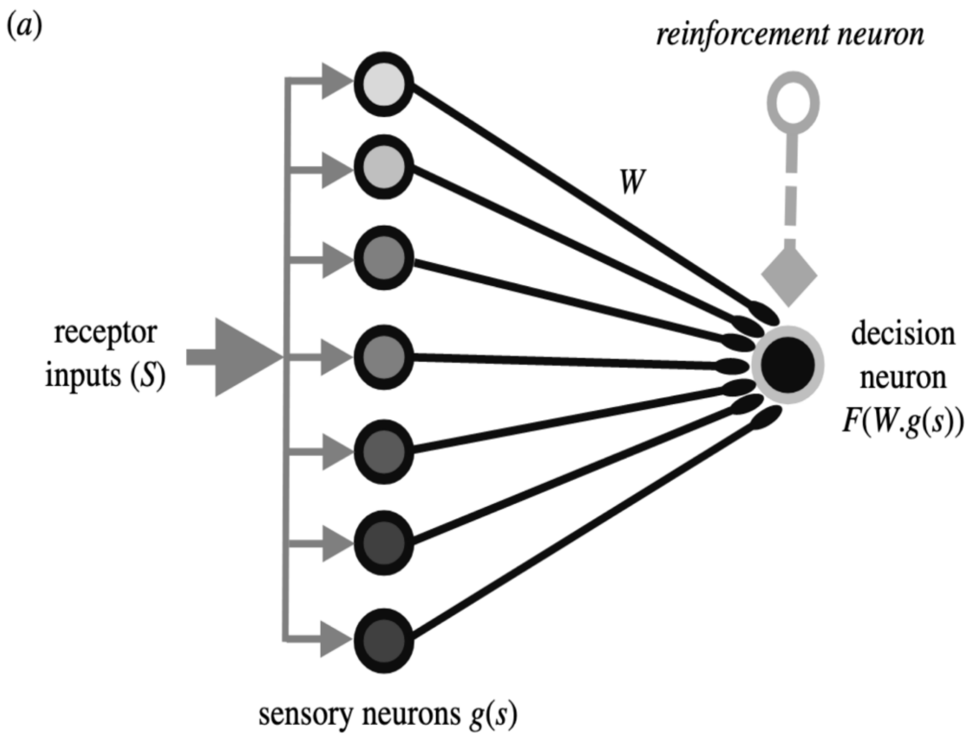
MaBouDi et al (2021)

Another way?



MaBouDi et al (2021)

Can a neural net that encodes spatial frequency do it?



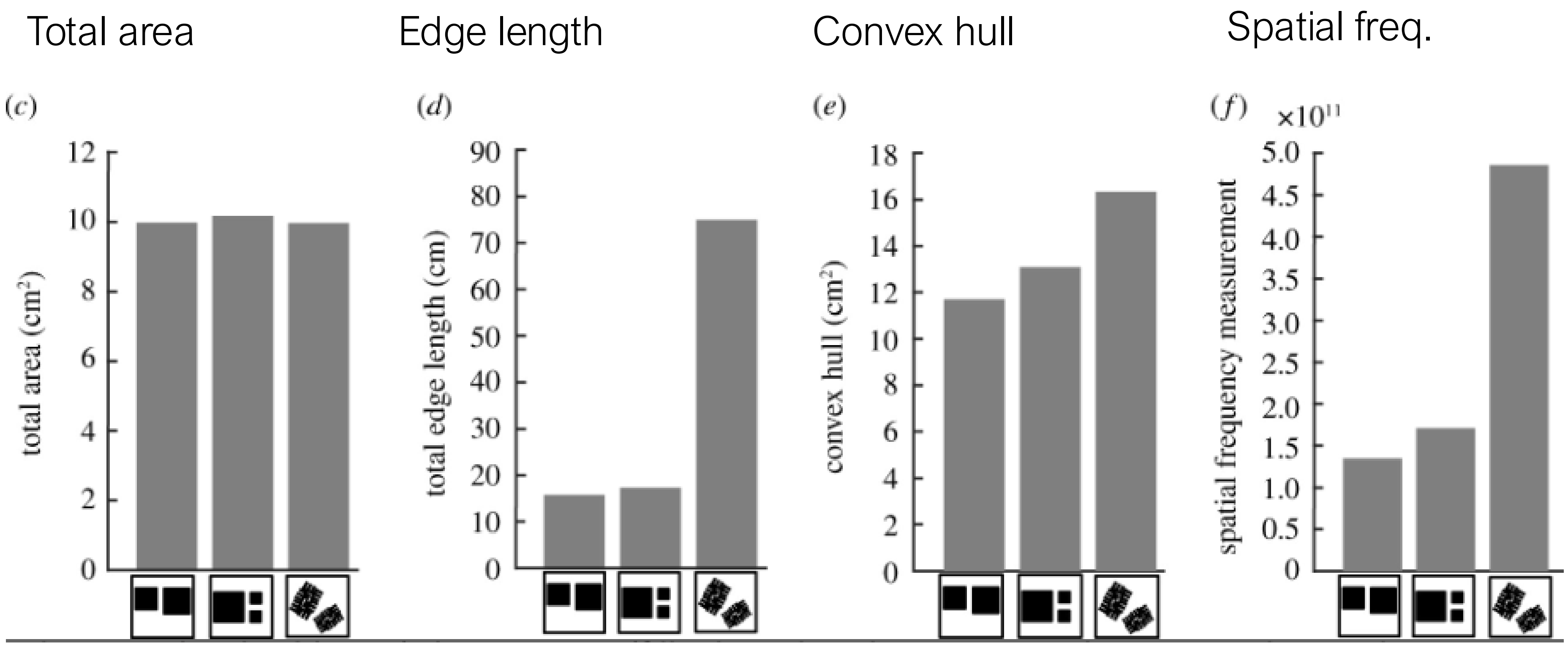
Each sensory neuron has a different "preferred" spatial frequency

The decision neuron determines the estimated spatial frequency

Comparisons are then decision neuron output for S1 – for S2

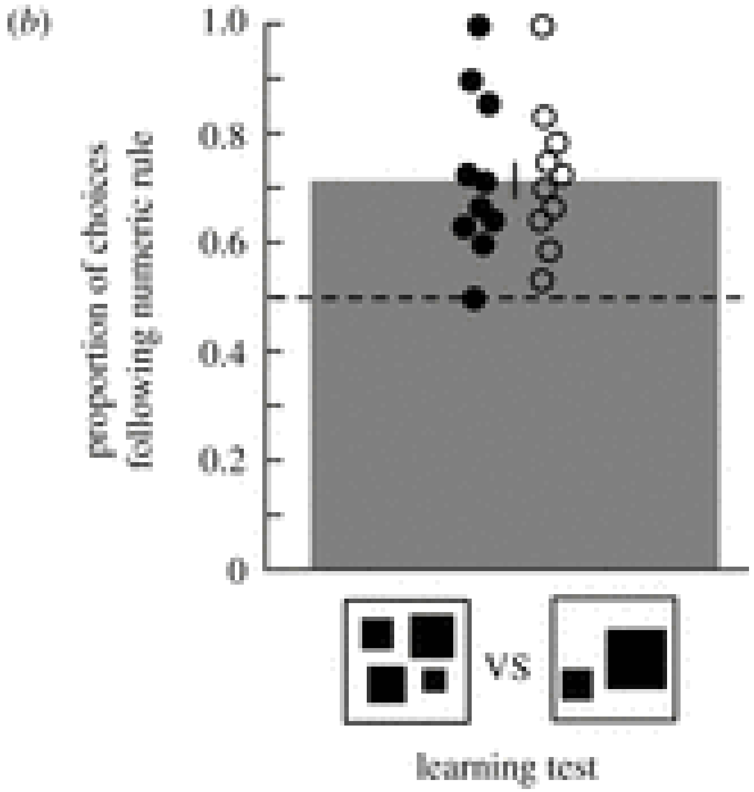
MaBouDi et al (2021)

Stimuli used in the experiment



MaBouDi et al (2021)

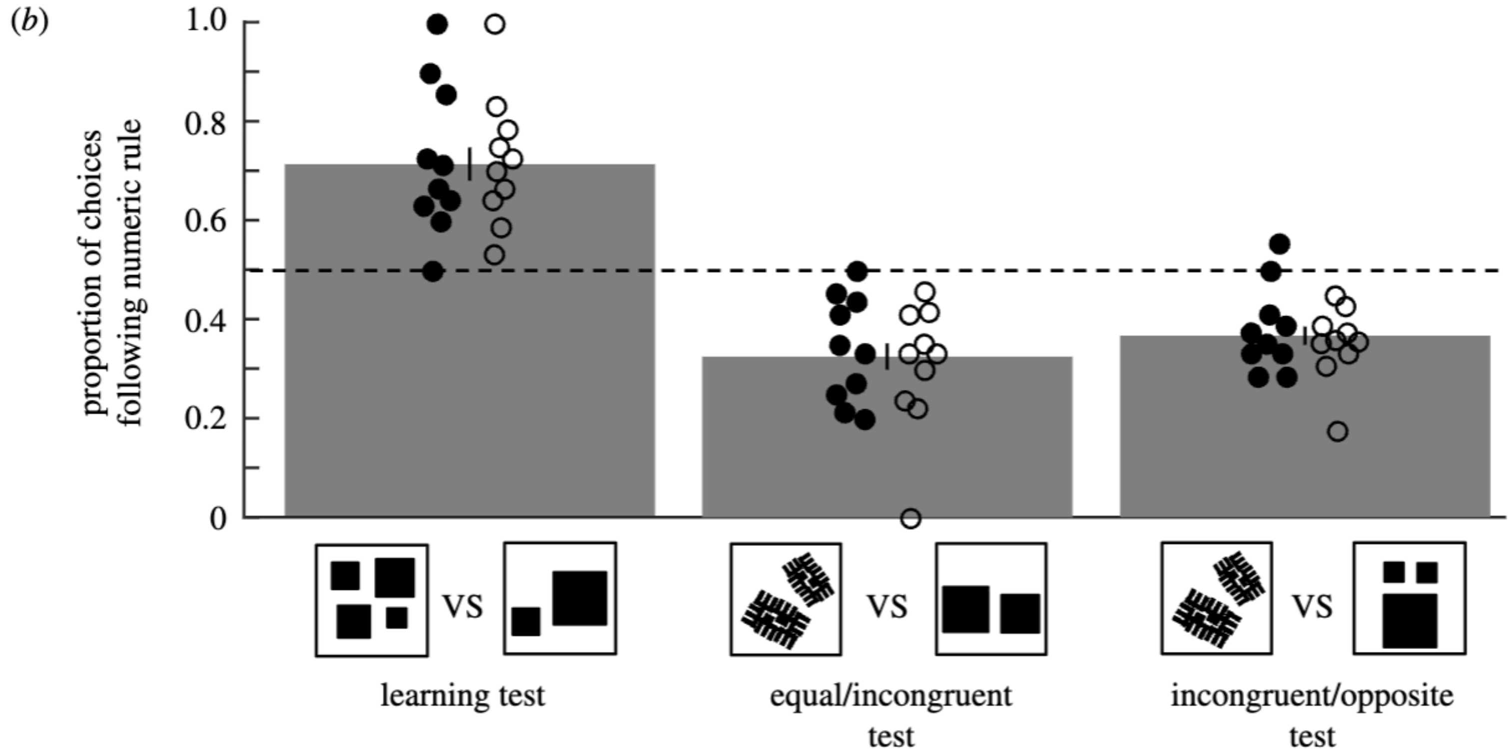
Addition & subtraction in bees



Bees could learn to do the task

MaBouDi et al (2021)

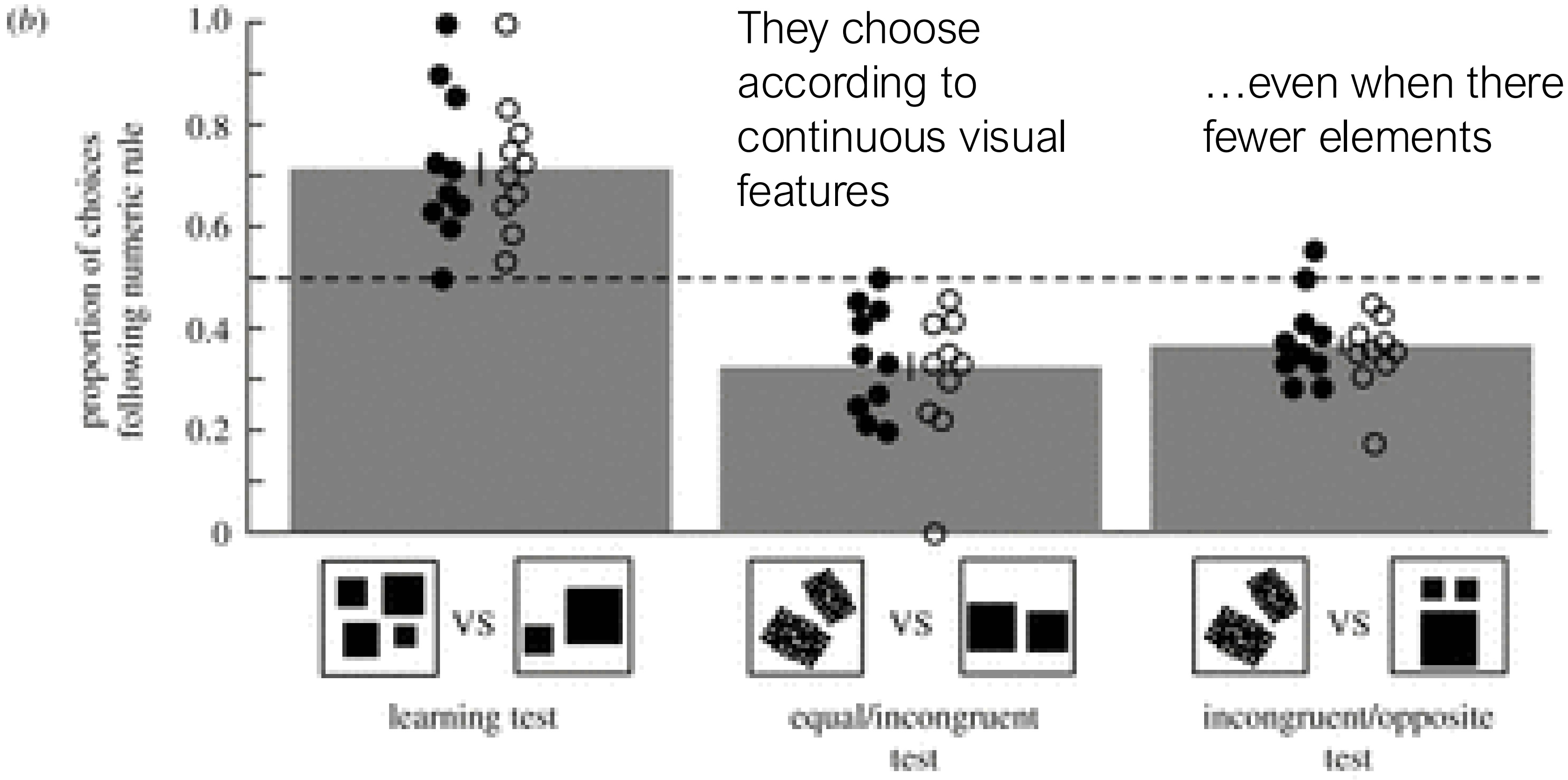
Addition & subtraction in bees



…but given the option, they will choose according to continuous cues rather than number

MaBouDi et al (2021)

Addition & subtraction in bees

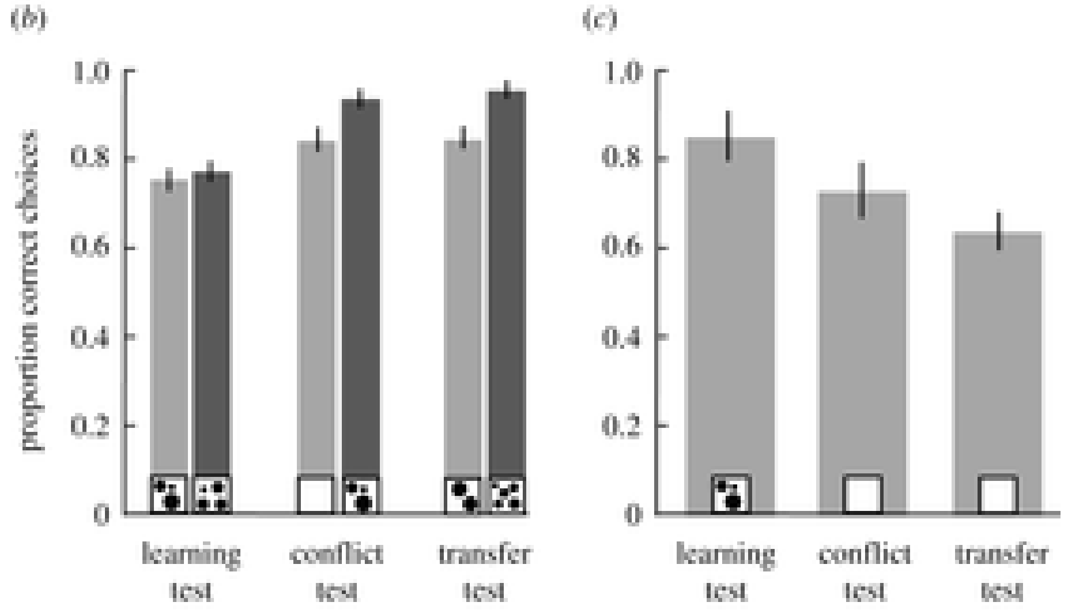


They choose according to continuous visual features

…even when there are fewer elements

MaBouDi et al (2021)

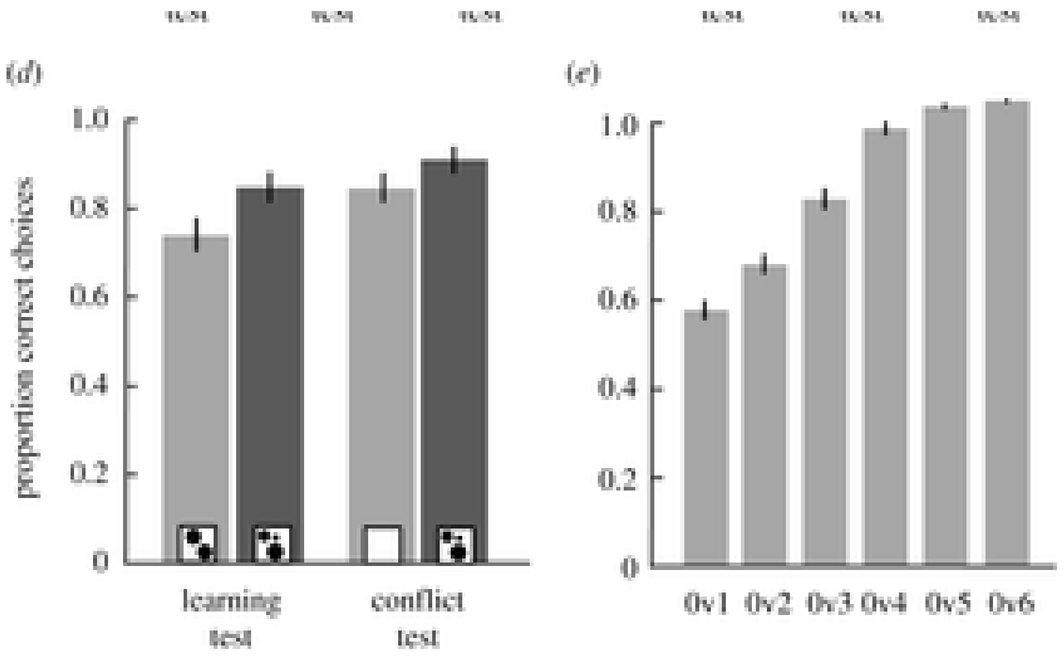
Neural network performance



The neural network model can:
(1) learn the task,
(2) even when the answer that was incorrect in training is now correct, and
(3) even when exposed to untrained “numbers”

MaBouDi et al (2021)

Neural network performance



The neural network model can derive the correct answer to tasks using zero

MaBouDi et al (2021)

Conclusion

A great example of how you can use modelling to address "how do they do that" questions!

Discussion

What do you think?

Are you convinced?

Can the neural network model do arithmetic?