Might visual clustering underlie numerosity estimation?

Vijay Marupudi, Shubh Goyal, Sashank Varma, & V.N. Vimal Rao

Georgia Tech

INTRODUCTION

- Human visual clustering: the process of dividing a set of points into "similar" groups.
- There are surprisingly few studies and models of this ability given its importance for human cognition.
- Visual density has been previously shown to predict perceived numerosity of a stimulus (Dakin et al., 2011; Gebuis & Reynvoet, 2012).
- People use visual density to estimate numerosity for dense point arrays (Anobile et al., 2013). This behavior follows a different psychophysical function than Weber's law.
- Research has shown that people use groups of points to enumerate a stimulus (Starkey & McCandliss, 2014), however recent work suggests that this might only occur when the groups have an even number of points per group (Ciccione & Dehaene, 2020).
- Additionally, people tend to underestimate the numerosity of a stimulus the more clustered it is (Allïk & Tuulmets, 1991; Chakravarthi & Bertamini, 2020; Chakravarthi et al., 2023; Im et al., 2016).
- Might people be using visual clustering processes, which have been shown to be a reliable ability (Marupudi & Varma, under review), for numerosity estimation? Is clustering part of the mechanism through which the brain understands number?

METHODS

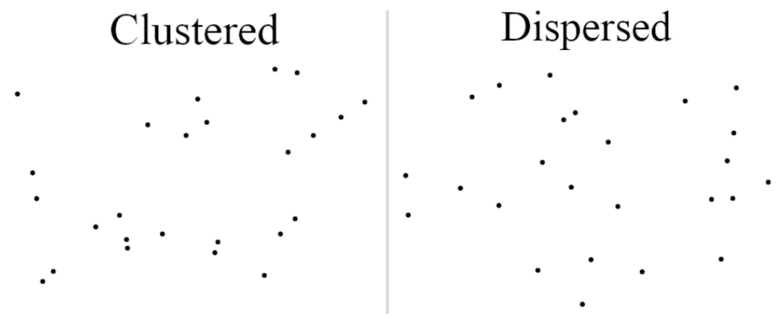
- N = 420 (85 excluded) undergraduate students at a large Midwestern university in the USA.
- We used 56 stimuli with 10-40 points, split into statistically clustered and dispersed sets.
- Participants completed 112 **magnitude comparisons** between all pairs (sides counterbalanced) of stimuli with numerosity ratios greater than 0.7.
- Of those, 56 comparisons were between clustered and dispersed stimuli.
- Of those, 24 magnitude comparisons between stimuli with the same number of points.
- Then, participants provided 56 **numerosity estimations**, one for each stimulus.
- Then, participants provided 56 **clusterings**, one for each stimulus, by drawing shapes around points.

Research questions

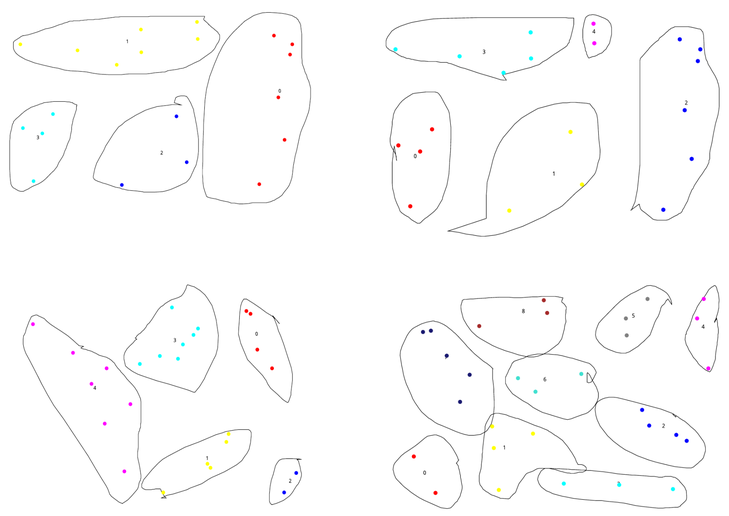
- **Do people use the number of clusters they see as a heuristic for determining numerosity?**
- **How does statistical cluster structure impact participants' magnitude comparisons and numerosity estimations?**

EXAMPLES

Stimuli

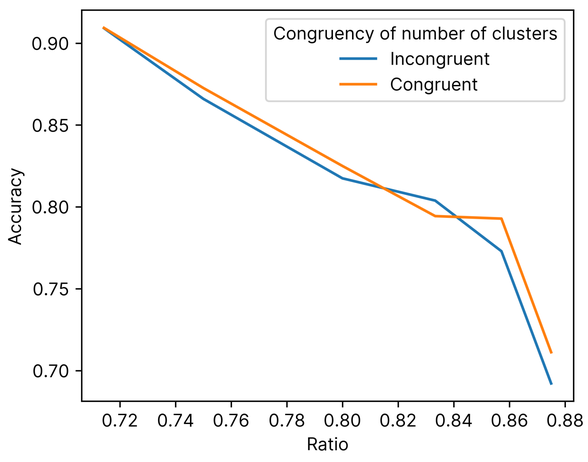


Example clusters

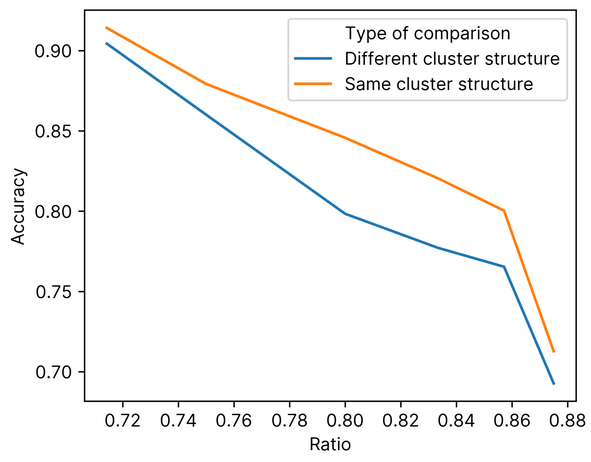


RESULTS

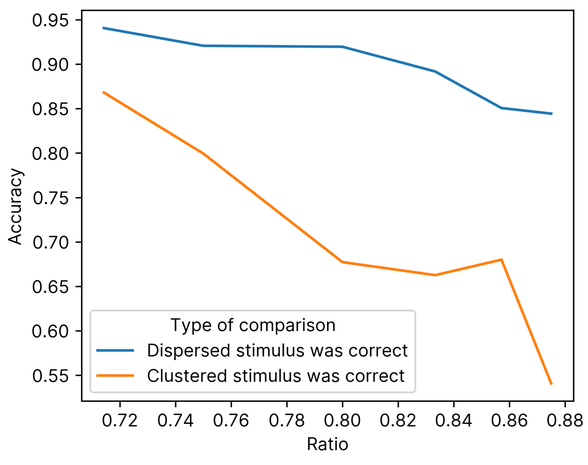
Magnitude comparison



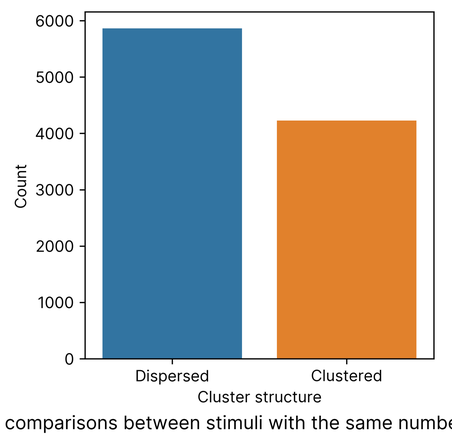
Congruent stimuli were the stimuli for which participants drew more clusters for the correct answer. The odds of participants being correct on congruent stimuli were 1.46 times the odds for incongruent stimuli (controlling for the ratio and the cluster structures of the stimuli)



The odds of participants being correct on comparisons between stimuli with the same cluster structure were 1.29 times the odds for stimuli with different cluster structure (controlling for the ratio and the number of drawn clusters)



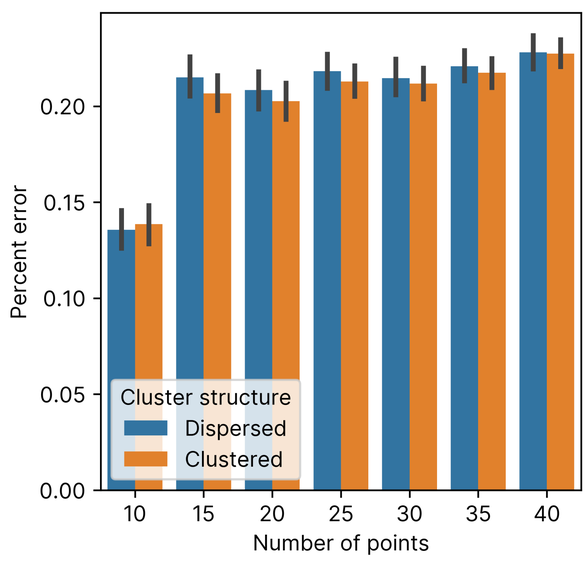
Among comparisons between stimuli with differing cluster structure, participants were overwhelmingly more accurate on comparisons where the dispersed stimulus was the correct answer.

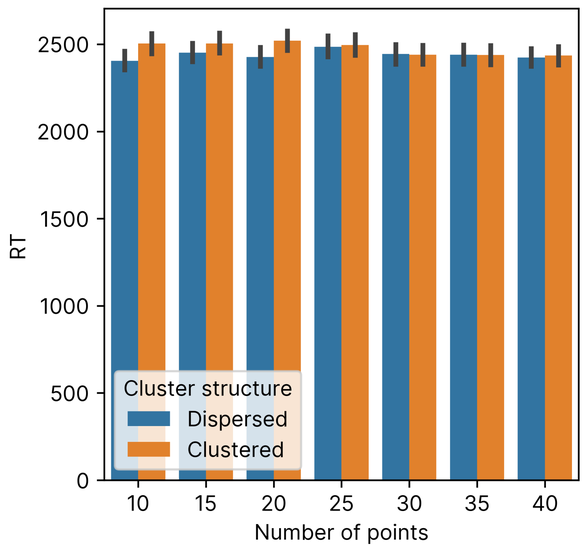


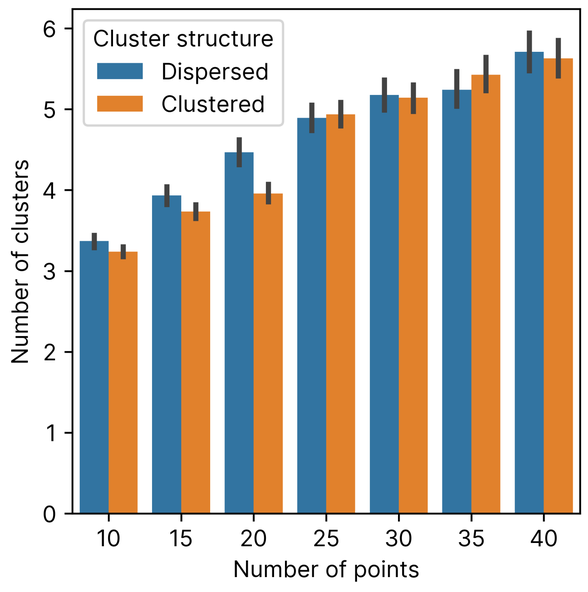
For comparisons between stimuli with the same number of points

Among comparisons between stimuli with the same number of points, participants chose the dispersed stimulus 58% of the time.

Magnitude estimation







- Cluster structure did not significantly predict accuracy or reaction time at magnitude estimation.
- However, each cluster drawn by participants was associated with a 0.4 percent increase in percent error ($p < 0.001$).
- This may be because the number of clusters is strongly associated with the number of points in a stimulus (see Figure to the left).

Discussion

- We found evidence that cluster structure is strongly associated with how people perceive numerosity in point arrays, consistent with prior work. Participants tend to perceive dispersed stimuli as more numerous than clustered stimuli.
- This difference is only apparent in the magnitude comparison task and not the magnitude estimation.
- The number of clusters drawn by participants is predictive of both magnitude comparison and magnitude estimation behavior.
- We intend to look more closely at the properties of participants' clusters in future work.