Attentional Selection of Multiple Correlation Ensembles

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Ensemble Coding

- Rapidly and accurately extract structural regularities from our visual environment

(Haberman & Whitney, 2012; Alvarez & Oliva, 2009)
Ensemble Coding

• Rapidly and accurately extract structural regularities from our visual environment

(Haberman & Whitney, 2012; Alvarez & Oliva, 2009)
Ensemble Coding

• How do we select or understand information about just the green leaves?
What drives attentional selection?

- Does combining features boost selection? (Moore & Egeth, 1997)
- Do color-category differences affect selection? (Nagy & Sanchez, 1990)
Correlations are Ensembles

- Rensink (2017)
Correlations are Ensembles

- Rensink (2017)

We can ask the same kinds of questions with scatterplots, like how we ignore these red things and attend to the green things. (Just like the leaves).
Implications for New Research

• Scatterplots are a useful, controlled stimuli for investigating multiple ensembles in attention
Which scatterplot has a higher correlation value?
General Methods

Which scatterplot has a higher correlation value?
• JNDs exhibit clear linear behavior
  – Instance of Weber’s Law

• Exact same behavior as other low-level visual quantities
  – Luminance, size, length, etc.

$k = \frac{jnd(r)}{(1/b - rA)}$

$k$ (slope) = precision

Rensink & Baldridge (2010)
Scatterplots as Visual Stimuli

- People’s abilities to perceive color differences varies significantly across mark types and sizes

(Szafir, 2017)
Color JNDs Differ by Stimuli Size

50% JND for Points

\[ ND_L(50\%, s) = 5.095 + \frac{0.80}{s}, R^2 = .93 \]
\[ ND_a(50\%, s) = 5.089 + \frac{2.69}{s}, R^2 = .99 \]
\[ ND_b(50\%, s) = 6.786 + \frac{3.20}{s}, R^2 > .99 \]

\[ ND_L(p, s) = \frac{p}{0.0937 - \frac{0.0085}{\text{diameter}}} \]
\[ ND_a(p, s) = \frac{p}{0.0775 - \frac{0.0121}{\text{diameter}}} \]
\[ ND_b(p, s) = \frac{p}{0.0611 - \frac{0.0096}{\text{diameter}}} \]

(Szafir, 2017)
Color Difference with $\Delta E$

Color difference is the distance $\Delta E$ between two values in color space.
Current Study

- Extend methods from Rensink & Baldridge (2010) to investigate perception of multi-class scatterplots

Experiment 1: Color & Shape
Experiment 2: Color Only
Color and Shape Stimuli

- Mark Size: \(0.35^\circ\) (8px on 27” iMac)
- Mark Shape: Squares and diamonds (orientation difference)
- Color Space: CIE L\(^*\)C\(^*\)h\(^*\) / CIE L\(^*\)a\(^*\)b\(^*\)
- Colors: Red, green, blue, and yellow
Defining our Experiment Colors

- 2 steps
- 1 step
Target color
+ 1 step
+ 2 steps

-ΔE
-ΔE
+ΔE
+ΔE

1 JND

ΔE_L = 7.33
ΔE_C = 15.48
ΔE_h = 15.48
Final Colors for Experiments

Luminance

Chromaticity

Hue
Experiment 1: Color & Shape

• Scatterplots contain both a "target" ensemble and an irrelevant “distractor” ensemble
• Ensembles defined by both color and shape
Experiment 1: Color & Shape

Luminance

Chromaticity

Hue

-ΔE  -ΔE  +ΔE  +ΔE  Other Target Colors

Target

Target

Target
Experiment 1: Color & Shape

Which scatterplot has a higher correlation value of red squares?
Experiment 1: Color & Shape

Which scatterplot has a higher correlation value of red squares?
Experiment 1: Results

Red - Luminance

JND

Pearsons r

Green (control)
-2
-1
1
2
Experiment 1: Results

Shape & Color Feature Task
(n = 27)

Color Difference
\(F(3, 51) = 1.34, p = .06\)

Color Difference X Correlation Value
\(F(3, 51) = .95, p = .58\)

No differences between the four colors at each level of correlation!
Experiment 1: Results

Shape & Color Feature Task
(n = 27)

Color Axis Difference
$F(2, 24) = 4.06, \ p = .02^*$

Best performance for colors separated along luminance axis!
Experiment 1: Summary

• Color-category does not affect discrimination performance for target ensembles

• Luminance axis is weighted differently
  – Helps selection and discrimination for shape differences
Question

• Are participants just using shape/orientation?
  – We already know people can do this…

Sun et al. (2015)
Experiment 2: Color Only

• Test ensembles separated **only** by color

• Include a single-population condition
  – Does second population causes interference at all?

Elliott & Rensink (VSS 2017)
Experiment 2: Color Only
Experiment 2: Color Only

Luminance

Chromaticity

Hue

Color Category

Target

Target

Target

Target

Target

Target

Target

Target
Experiment 2: Color Only

First, show participants the **target** color, as well as **distractor** colors.
Experiment 2: Color Only

Which scatterplot has a higher correlation value of the **target** red squares?
Except it looked like this...
Experiment 2: Results

Red Chromaticity

![Graph showing JND vs. Pearson's r for different colors. The graph includes lines for #aa6453, #bc5942, #dc391f, #eb1607, and a line for No Distractor.](image)
Experiment 2: Results

Shape & Color Feature Task
(n = 42)

Color Difference
\[ F(3, 51) = 2.38, \ p = .000 \ * \]

Color Difference X Correlation Value
\[ F(3, 51) = .87, \ p = .70 \]

Including a distractor population of data causes interference, no differences between colors!
Experiment 2: Results

Shape & Color Feature Task (n = 42)

Color Axis Difference $F(2, 24) = 1.07, p = .35$

No effect of color axis.
Experiment 2: Summary

• People can successfully select and discriminate ensembles defined by **color only**
  – Even when those colors are extremely perceptually similar (1 JND)

• Any color dimension can be used equally well for ensemble selection
Conclusions

• Overall performance was equally good for target ensembles defined by differences in single features and differences in two features
  – But, presence of distractors causes interference for selection of targets

• Even very small differences along each color dimension were enough to facilitate ensemble selection

• Increasing feature differences did not boost selection performance
  – Caveat: it does appear to help people use luminance dimension
Future Directions

• Scatterplots are convenient, well-controlled stimuli for investigating the nature of ensemble processing in attention

• Our color modeling technique can be applied to other multi-dimension discrimination and identification tasks in attention
  • Number, centroid-detection, array-density tasks…

• Inform color palette design choices for visualization software
Thank You!

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