Scale-invariance for radial frequency patterns in peripheral vision

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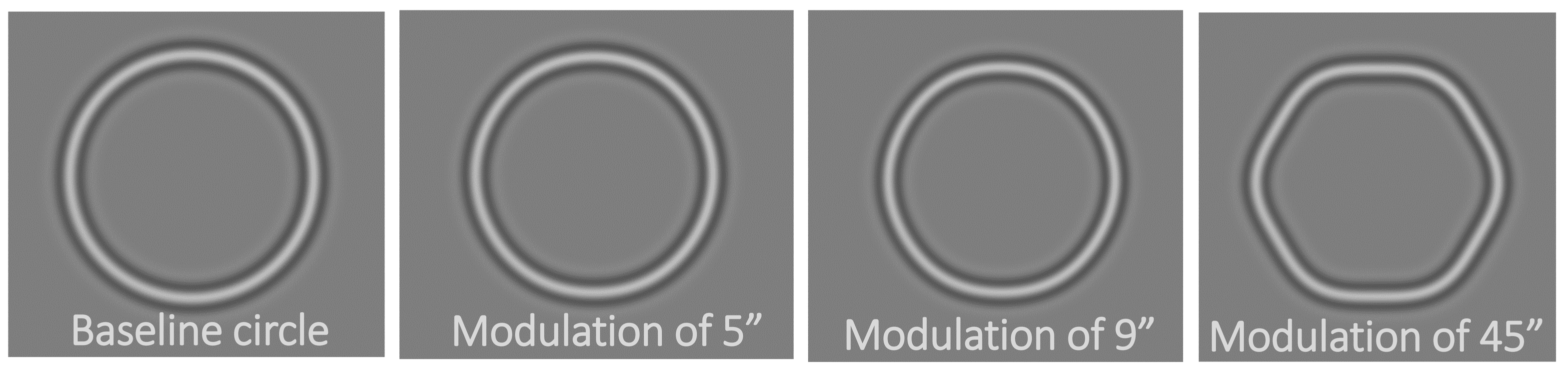
1. Background

Shape Discrimination Hyperacuity (SDH):

- The ability to discriminate between circles and sinusoidally deformed circles called **Radial Frequency patterns** (Wilkinson et al., 1998) that goes beyond visual acuity resolution (*in central visual field: **2-15"** = 0.0005 ° – 0.004 °*)



! As many visual functions, SDH performance decreases with eccentricity:

central SDH **>** **peripheral** SDH

Size-scaling of peripheral patterns

central SDH **=** **peripheral** SDH

(Achtman, Hess and Wang, 2000)

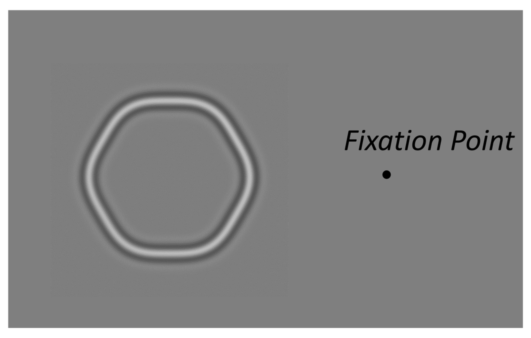


Fig.1. Eccentric presentation of a peripheral stimuli

However:

! When scaling is performed for each eccentricity, large scaled patterns fall into a range of eccentricities rather than one specific location. Thus some parts of a pattern are under-scaled and some are over-scaled.

! Scaling factors smaller than the Cortical Magnification Factor (CMF) have been found to maintain the same level of performance when expressed in Weber Fractions (WF=$\frac{\text{Modulation}}{\text{Radius}}$) (Żołubak and Garcia-Suarez, 2018).

? There is no single exclusive size of a pattern for each eccentricity – *is there peripheral scale invariance for Radial Frequency patterns?*

Scale invariance: extraction of shape independently of its spatial scales and location:

showed for RF patterns in concentric (central) presentation

(Mullen & Beaudot, 2002; Mullen, Beaudot, & Ivanov, 2011; Wilkinson, Wilson, & Habak, 1998)

2. Aim

To investigate scale invariance for SDH in peripheral vision by using stimuli size-scaled with five scaling factors smaller than Cortical Magnification Factor (CMF).

3. Method

Stimuli: 4th derivative of Gaussian (D4) **Baseline Circles** and **Radial Frequency patterns** (Wilkinson and Wilson, 1996; Wilkinson et al., 1998) generated in MATLAB (MathWorks, Inc.). The latter obtained by applying a sinusoidal modulation to the radius of a baseline circle.

Task: to discriminate circles and Radial Frequency patterns (*fig.2*); both characterised by peak spatial frequency 1 and 5 c/deg., frequency 6 cycles and contrast 50%.

Paradigm:

Stimuli were displayed in a CRT monitor using the visage system (CRS) at **5°**, **10°**, **15°** and **20°** to the left visual field.

Modulation thresholds (MT) were established as an average of last five reversals in the staircase out of six. For each condition, thresholds were repeated at least 4 times.

Participants (N=5), aged 24-35 years old performed the task monocularly with a right eye in a dark room.

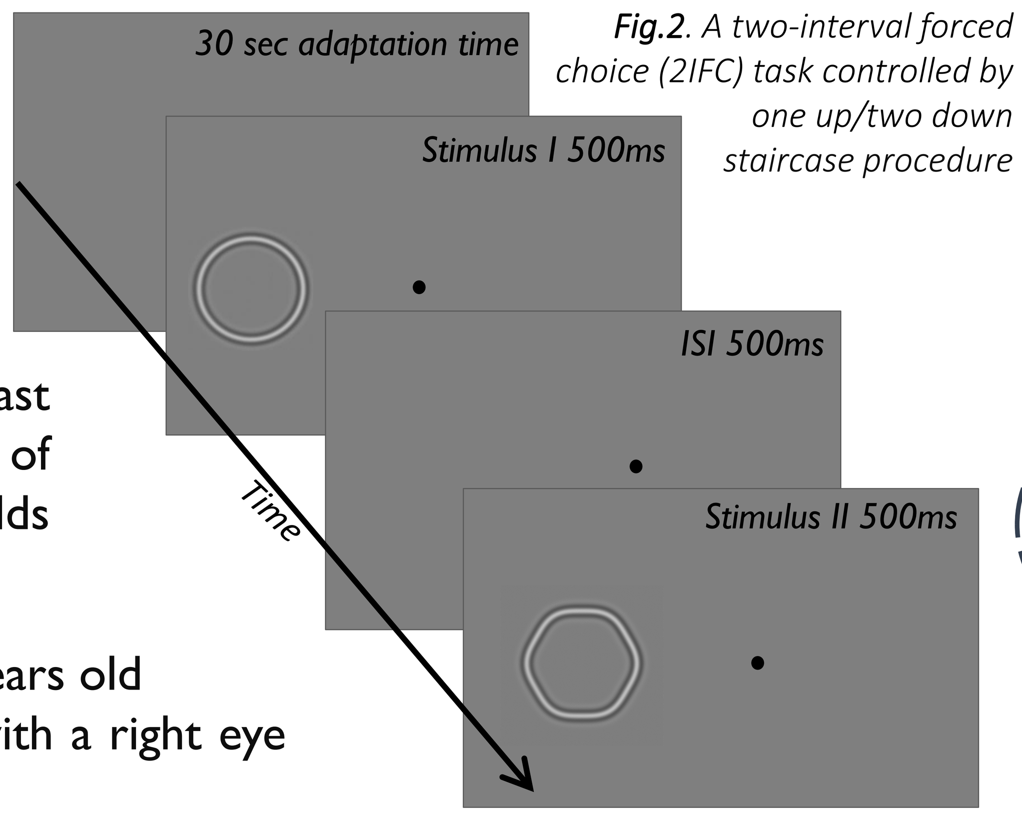
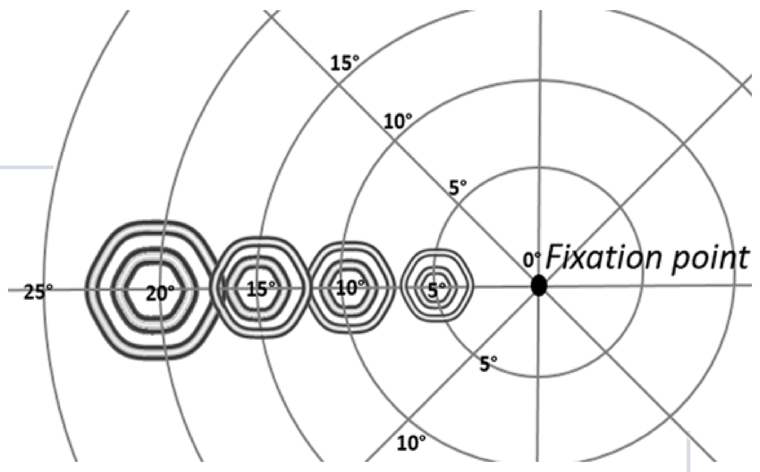


***Fig.2.** A two-interval forced choice (2IFC) task controlled by one up/two down staircase procedure*

Method

Scaling

Radii of peripheral stimuli were scaled (*tab.1*) using **six scaling factors** derived from the **CMF** $((1 + 0.33E + 0.00007E^3)^{-1} \times 7.99$ (0< E <60°))



Hence, at each eccentricity seven different in size patterns were presented:

Eccentricity	Unscaled	MF1 0.125 CMF	MF2 0.25 CMF	MF3 0.5 CMF	MF4 0.75 CMF	MF5 0.875 CMF	CMF
0°	1.2	-	-	0.6	-	-	1.2
5°	1.2	0.4	0.8	1.6	2.38	2.78	3.18
10°	1.2	0.75	1.3	2.6	3.93	4.58	5.24
15°	1.2	0.9	1.8	3.71	5.56	6.49	7.42
20°	1.2	1.25	2.45	4.9	7.34	8.55	9.79

Table I. Scaled radii of peripheral stimuli (degrees)

4. Results:

Averaged Modulation Thresholds (N=4)

- As expected, Weber Fractions (*fig.3A*) for the **unscaled stimuli** increased with eccentricity ($F(3,15)=7.49$, $p=0.003$).
- **Scaling of the peripheral stimuli** with MF1-CMF (*fig.3A*) resulted in constant WF across the temporal retina ($F(3,88)=1.55$, $p=0.21$), however levels of performance differed ($F(5,88)=42.82$, $p<0.001$):
  - Thresholds for MF1, MF2 and MF3 were higher than those for larger factors (MF4-CMF).
  - Thresholds for the larger factors MF4 to CMF did not differ significantly ($F(2,44)=2.76$, $p=0.074$).
- Modulation sizes increased linearly with eccentricity (*fig.3B*) ($F(3,100)=60.2$, $p<0.001$) and remained within the hyperacuity range. At each eccentricity, thresholds were alike regardless of the stimulus size, except for CMF-scaled patterns where they were higher ($F(6,100)=8.37$, $p<0.001$).

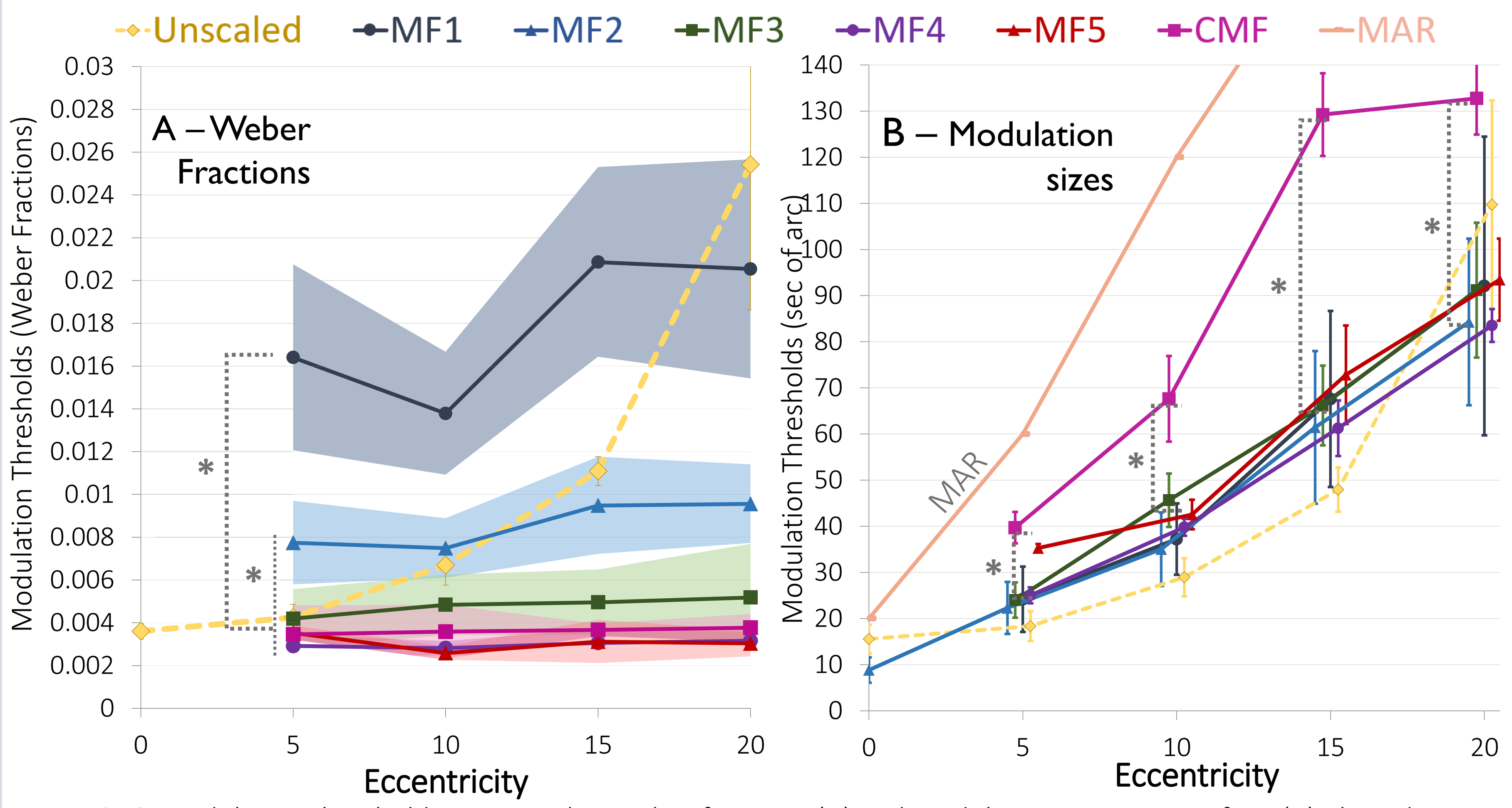


***Fig.3**. Modulation thresholds expressed in Weber fractions (A) and modulation sizes in sec of arc (B) plotted against eccentricity. Shaded areas (A) and error bars (B) show Standard Error of the Mean (±1SEM) and asterisks mark the significant differences in modulation thresholds (p<0.05).*

Discussion

Modulation size of peripheral patterns is determined by two factors:

- **Proportion of baseline radius to modulation size** ≥ 0.003
- **Minimal Modulation** (MM) size specific to each eccentricity.

→ Once the modulation size equals or exceeds MM for a given eccentricity (as in case of M4-CMF), SDH performance is based solely on the proportion between radius and modulation.

→ When smaller radii are used (MF1-MF3), their modulations, which originate from the 0.003 proportion, are too small and need to be increased until MM is reached. This results in elevated WF for smaller MFs.

5. Conclusions

- For tested parameters, there is peripheral scale invariance for Radial Frequency patterns across temporal retina up to 20°;
- However its scope is limited by the value of the minimal modulation (MM) specific to each eccentricity.

References

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