Lighting from above prior in the perception of biological motion: new illusion and a neural model

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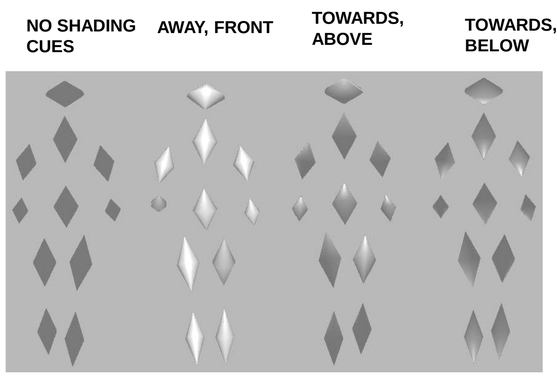
Introduction

- Surface shading is a highly significant depth cue in static shape encoding (Yamane 2008, Tsutsui 2001, 2002).
- There is a bias in perceived light source position (Brewster 1847, Ramachandran 1988, Adams et. al. 2004, Stone et. al. 2009)
- The perception of body motion has been modelled using physiologically plausible architectures, building on form and motion detectors (Giese & Poggio, 2003; Lange, 2006).
- Using novel biological motion stimuli, consisting of volumetric elements with controlled lighting and surface reflectance, we have found a new perceptual illusion that demonstrates a 'lighting-from-above prior' in biological motion processing.

Goals

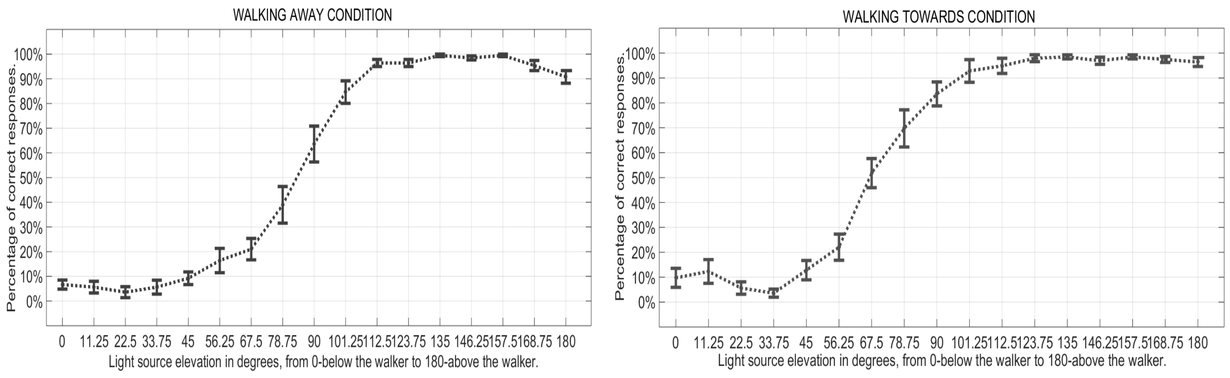
- **Psychophysically investigate the influence of shading on body motion perception.**
- **Determine psychophysically the critical features that determine the perception of walking direction from shading cues.**
- **Develop a model that implements a shading pathway that supports body motion perception from volumetric stimuli and that reproduces / explains perceptual the illusion.**

Experiment 1: influence of lighting



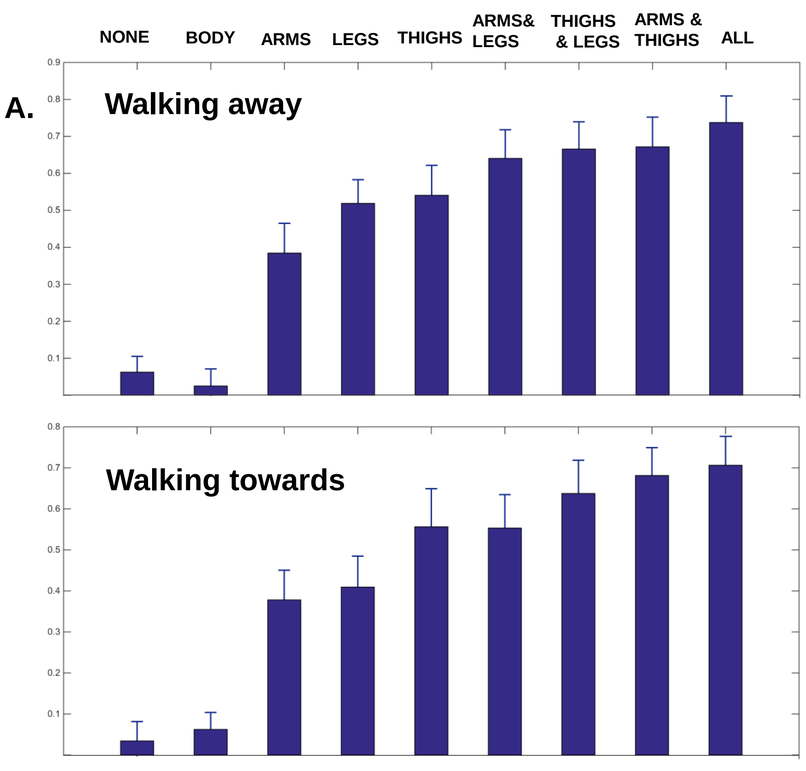
- 17 positions of the light source along the vertical meridian
- 2 walking directions (away, below)
- Question: "Is walker walking towards you or away"?
- 15 repetitions, 12 subjects (5 male, 7 female)

Results

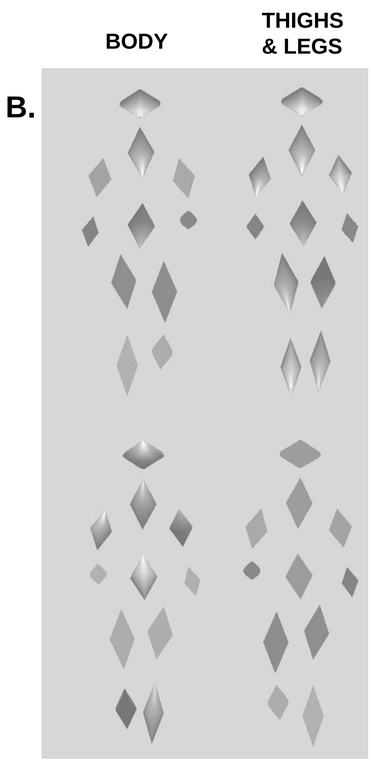


- Systematic variation of perceived walking direction with light source position (separate ANOVA's for TOWARDS and AWAY conditions: TOWARDS: $F(16,176) = 154.3$ and AWAY: $F(16,176) = 178.9$, $p<0.01$).
- No significant difference between AWAY and TOWARDS conditions ($F(1,11)= 1.0$, $p>0.05$); significant effect of light source position ($F(16,176)=140.5$, $p<0.01$), and significant interaction ($F(16,176) = 65.3$, $p<0.01$).
- **Conclusion: New Illusion: light source direction flips perceived walking direction.**

Experiment 2: critical features



A. Probability difference between illumination conditions for different feature combinations.



B. Snapshots from different reduced shading conditions.

- 2 light source positions; 9 feature combinations (presenting shading only on subsets of walker components); 2 walking directions; question: "Is walker walking towards you or away"?; 20 repetitions, 16 subjects
- 1-factor ANOVA on probability difference between illumination conditions (Tukey post-hoc test): significant differences between BODY and all other conditions $p<0.01$.
- No significant difference between conditions where least ARMS, LEGS or THIGHS were shaded; $p > 0.05$.
- **Conclusion: Influence of illumination direction conveyed though ARMS, THIGHS and LEGS shading, but not through BODY shading (despite of strong and visible shading gradients).**

2D Neural Field for Motion Pattern encoding

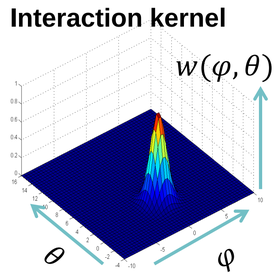
$$\tau_u \dot{u}(\varphi,\theta,t) = -u(\varphi,\theta,t) + w(\varphi,\theta) * 1(u(\varphi,\theta,t)) + s(\varphi,\theta,t) - h \quad \text{(Giese 2014)}$$

$$-\alpha a(\varphi,\theta,t) + \varepsilon(\varphi,\theta,t);$$

$$\tau_a \dot{a}(\varphi,\theta,t) = -a(\varphi,\theta,t) + 1\big(u(\varphi,\theta,t)\big);$$

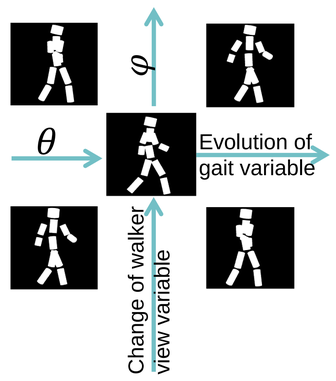
u: membrane potential; **s:** shape detector output; **θ:** snapshot no.; **φ :** view angle; w: interaction kernel; **h:** resting potential; ***:** convolution; **a:** adaptation state variable; **ε:** Gaussian noise process

Interaction kernel

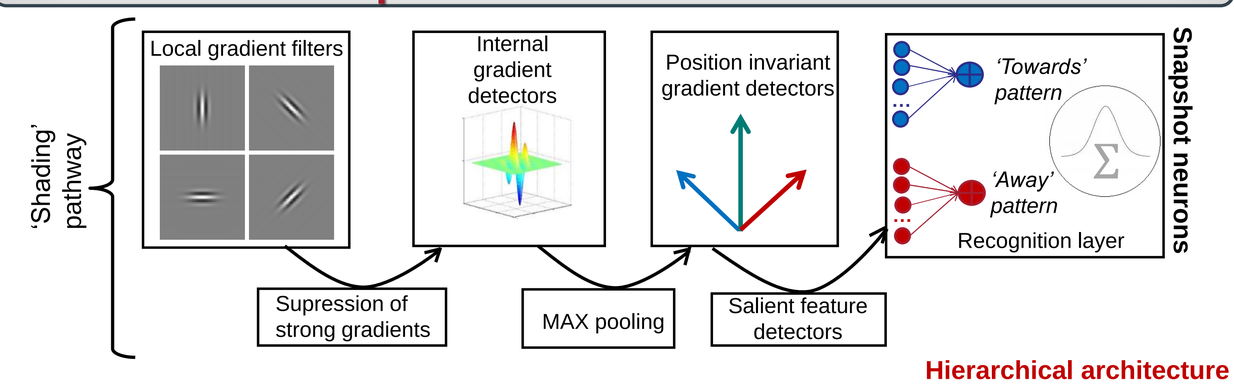


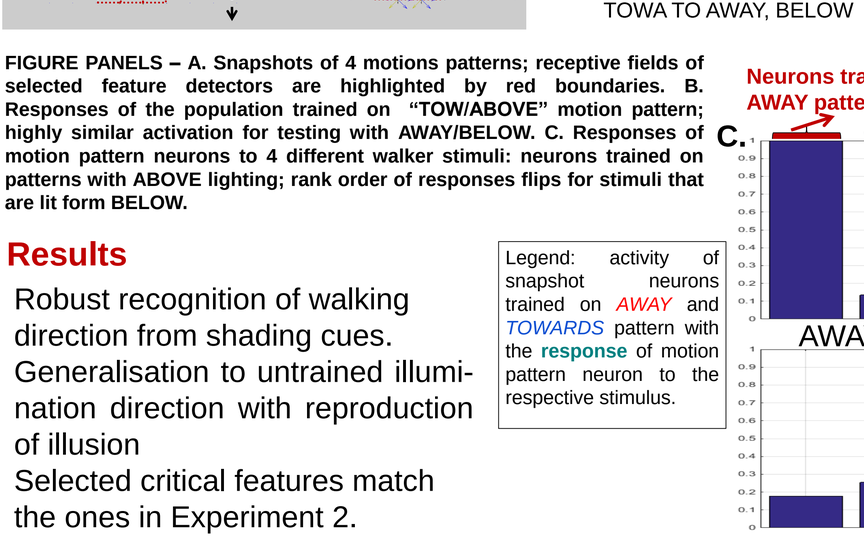
Asymmetric kernel with sequence selectivity (Amari 1977, Xie & Giese 2002, Zhang 1996).

Field dimensions



Extension: computational model for new illusion





Hierarchical architecture

- Analysis of internal illumination gradients
- 1st level: uneven Gabor filters
- Suppression of strong outer gradients by gating
- MAX pooling to increase position invariance
- Feature selection (unsupervised)

Outputs of different levels of the architecture for one body snapshot.

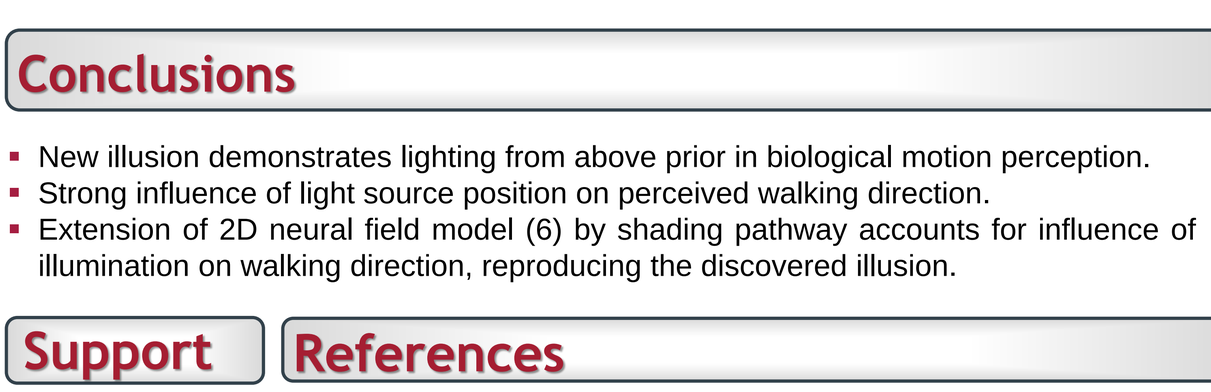
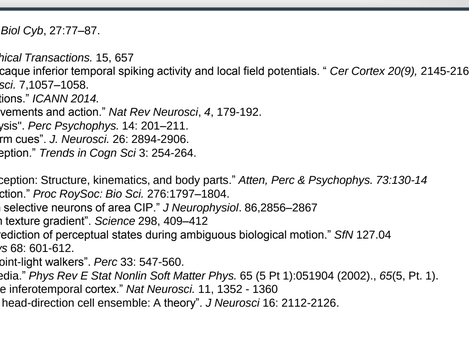


FIGURE PANELS – A. Snapshots of 4 motions patterns; receptive fields of selected feature detectors are highlighted by red boundaries. B. Responses of the population trained on "TOW/ABOVE" motion pattern; highly similar activation for testing with AWAY/BELOW. C. Responses of motion pattern neurons to 4 different walker stimuli: neurons trained on patterns with ABOVE lighting; rank order of responses flips for stimuli that are lit form BELOW.

Results

- Robust recognition of walking direction from shading cues.
- Generalisation to untrained illumination direction with reproduction of illusion
- Selected critical features match the ones in Experiment 2.

Legend: activity of snapshot neurons trained on *AWAY* and *TOWARDS* pattern with the **response** of motion pattern neuron to the respective stimulus.



Conclusions

- New illusion demonstrates lighting from above prior in biological motion perception.
- Strong influence of light source position on perceived walking direction.
- Extension of 2D neural field model (6) by shading pathway accounts for influence of illumination on walking direction, reproducing the discovered illusion.

Support

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