Neural model of biological motion recognition based on shading cues

Graduate School of Neural & Behavioural Sciences, International Max Planck Research School
Hertie-Institut für klinische Hirnforschung
Universitätsklinikum Tübingen
CIN Werner Reichardt Centre for Integrative Neuroscience
Eberhard Karls Universität Tübingen

Leonid Fedorov* and Martin Giese*

* Section for Computational Sensomotorics, Department of Cognitive Neurology, Hertie Institute for Clinical Brain Research, Centre for Integrative Neuroscience, University Clinic Tübingen, Tübingen, Germany.

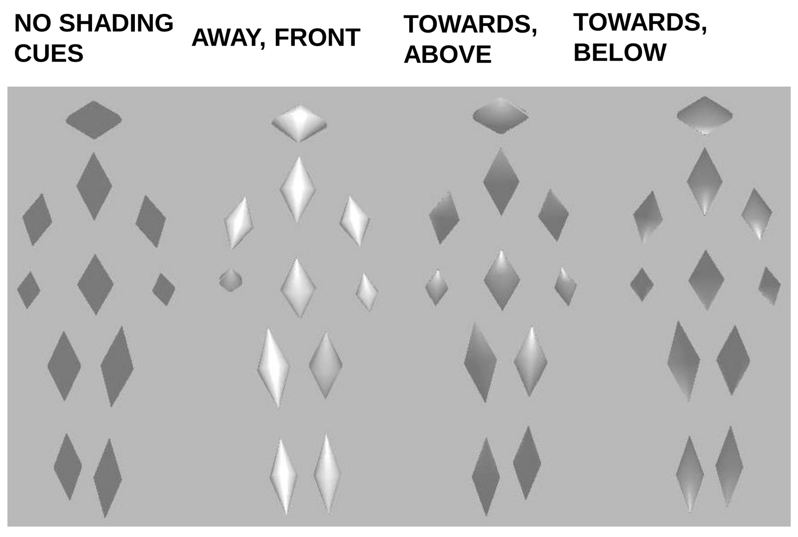
Introduction

- 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.

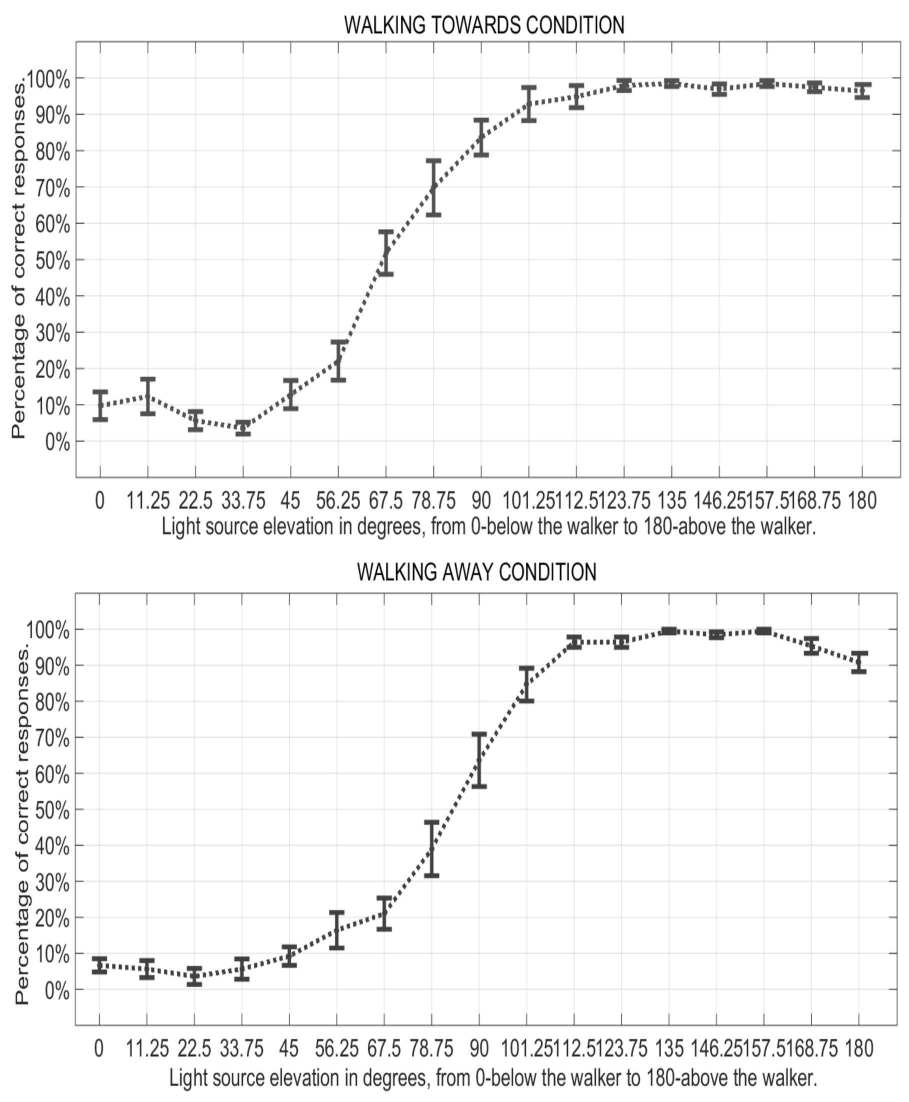
Goals

- **Psychophysically investigate the influence of shading on body motion perception and investigate critical features that determine the perception of walking direction**
- **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



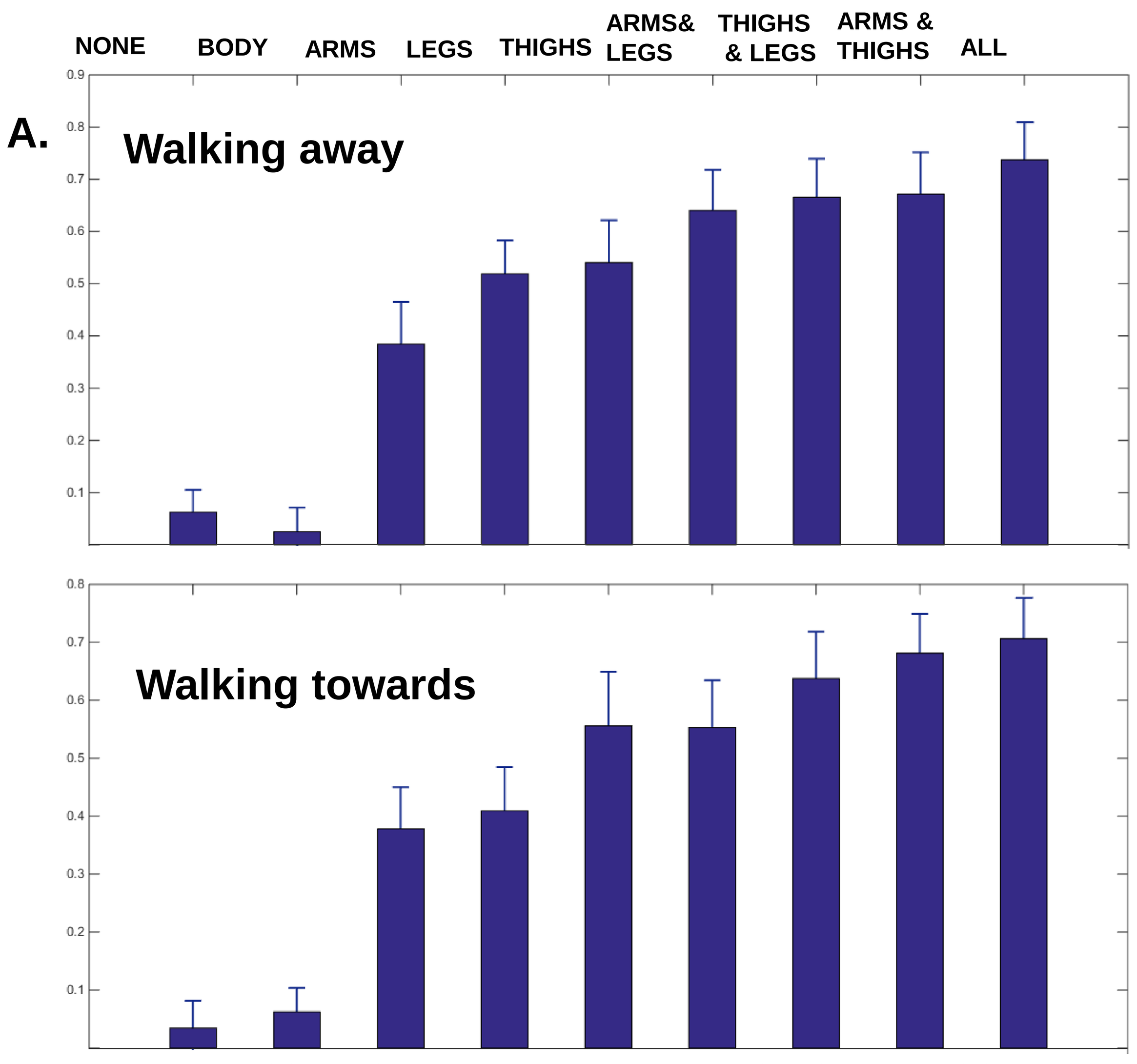
- 17 positions of the light source along the vertical meridian
- 2 walking directions (away, below)
- Question: "Is walker walking towards you or away"?
- 15 repetitions, 12 subjects (5 male, 7 female)



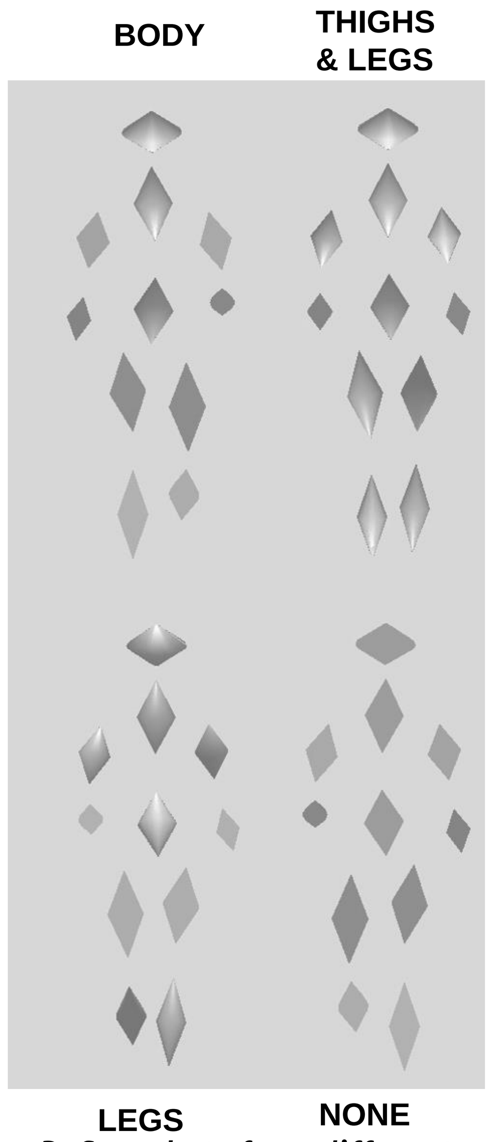
Results

- 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.

Results

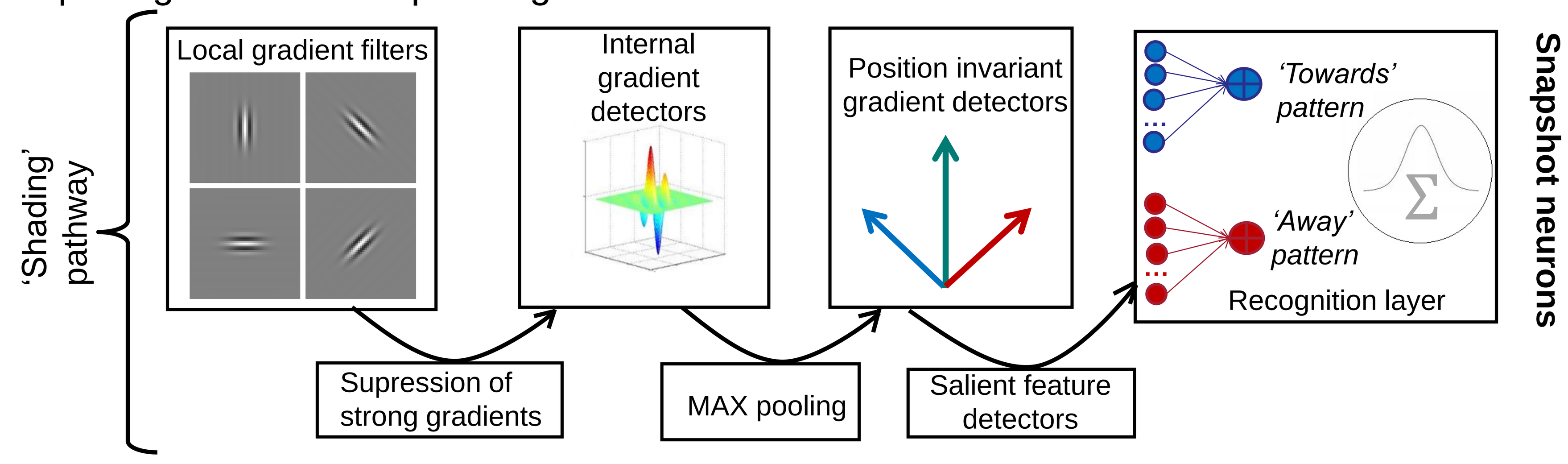
- 2 light source positions; 9 feature combinations (presenting shading only on subsets of walker components); 2 walking directions; question: "Is walker walking towards you or away?"; 20 repetitions, 16 subjects
- 1-factor ANOVA on probability difference between illumination conditions (Tukey post-hoc 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).**

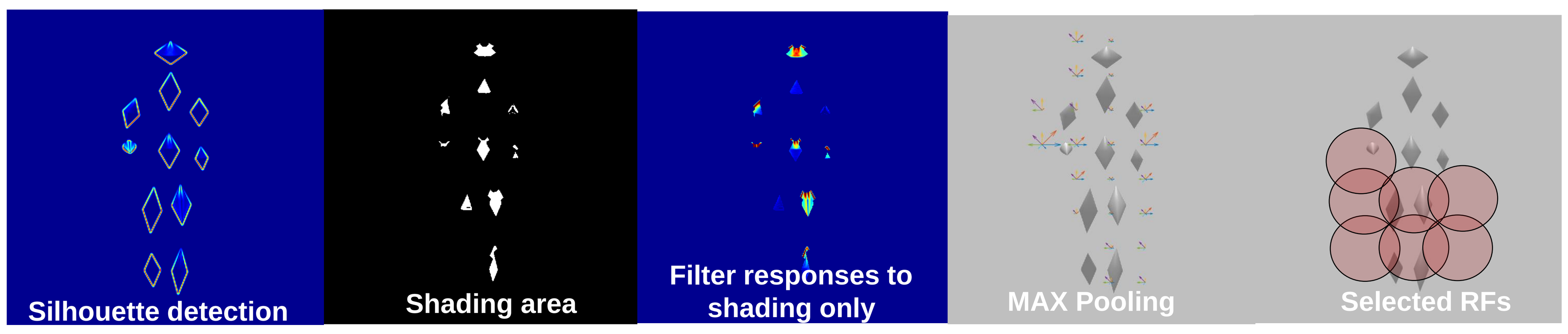
Model

Hierarchical architecture of the shading pathway

- Uneven Gabor filters detect local luminance gradients
- Strong boundary gradients suppressed by gating mechanism.
- Pooling of direction-specific population responses using MAX operation ⇒ partial position invariance.
- Feature selection: retain shading sensitive cells with high temporal variation
- RBFs for the recognition of frame-specific (internal) shading patterns.
- Detectors for TOWARDS and AWAY motion sum output signals of corresponding RBF units.

$$\begin{cases} G^{\psi} = exp\left(-\frac{\hat{x}^2+\gamma^2\hat{y}^2}{2\sigma^2}\right)\sin\left(2\pi\frac{\hat{x}}{\omega}+\upsilon\right) \\ \psi \in (1,\dots,\Psi) - index\ of\ the\ filter\ orientation\ \beta_{\psi} \\ \hat{x} = x\cos\beta_{\psi} + y\sin\beta_{\psi} \\ \hat{y} = -x\sin\beta_{\psi} + y\cos\beta_{\psi} \end{cases}$$



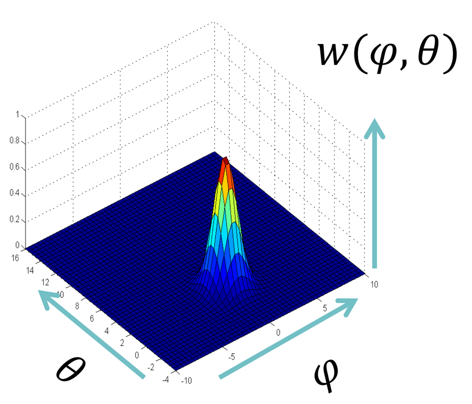


2D Neural field for motion pattern encoding

$$\frac{\partial u}{\partial t}(\varphi,\theta,t) = -u(\varphi,\theta,t) + w(\varphi,\theta) * H(u(\varphi,\theta,t)) + s(\varphi,\theta,t) \ - h$$

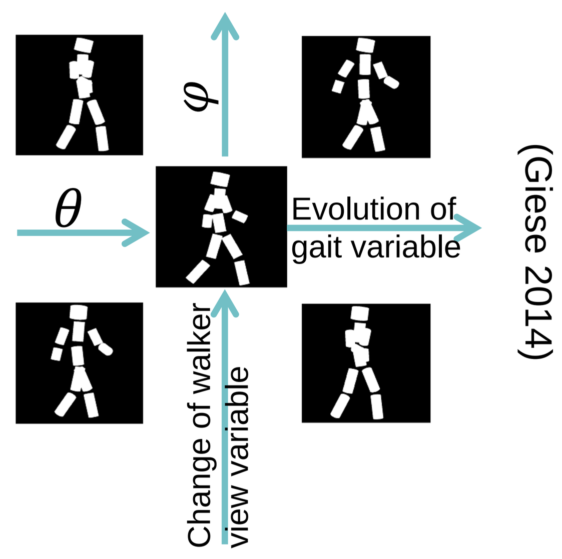
where
u – field activity;
s – output of shape detectors;
φ – view angle;
w – interaction kernel;
h – resting activity;
θ – snapshot number

Interaction kernel



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

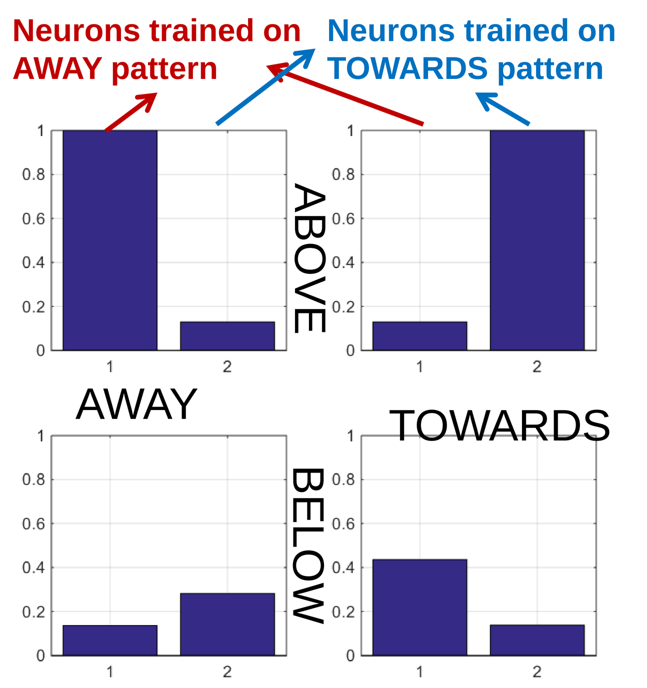
Field dimensions



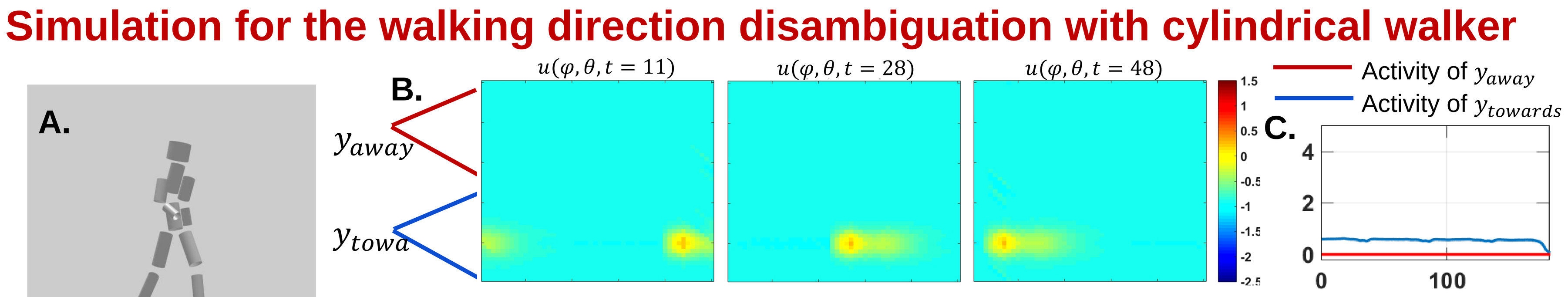
Simulation for the illusory effect with the diamond walker

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

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.



Simulation for the walking direction disambiguation with cylindrical walker



Legend: **A.** Snapshot of cylindrical walker facing angle $\frac{\pi}{4}$, deviating from the *TOWARDS* view. **B.** Field activity in response to cylindrical walker **C.** Activity of recognition neurons disambiguating the walking direction.

Results

- Robust recognition of walking direction from shading cues (Vangeneugden, 2012).
- Generalisation to untrained illumination direction with reproduction of illusion
- Selected critical features coarsely match the ones in Experiment 2.

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 (Giese, 2003) by shading pathway accounts for influence of illumination on walking direction, reproducing the discovered illusion.

Support

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