A Prior for Convexity can Override the Rigidity Assumption in Structure-From-Motion

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Background

- SFM is the ability to perceptually infer the 3D structure of an object from 2D image motion.
- The rigidity assumption, ubiquitous in the study of SFM, states that whenever a rigid interpretation is available the visual system will take that interpretation [1].
- Some studies have shown that rigidity is not necessary for SFM: observers can perceive the structure of non-rigidly transforming objects [2][3].
- Violations of the rigidity assumption, non-rigid interpretations of rigidly moving objects, have also been observed in the literature [4].

Motivation

Current Study: We investigate a perceptual phenomenon where the rigidity assumption is strongly violated: a rigidly rotating plane with concave and convex parts is perceived as moving non-rigidly.

Competition between priors:

- We believe this violation of the rigidity assumption is due to competition between priors for **rigidity** and **convexity**.
- In cases where the priors are in conflict:
  - When the **convexity prior** wins (both parts seen as convex) the object is "misperceived" as moving non-rigidly.
  - When the **rigidity prior** wins (objects seen rotating rigidly) the surface geometry is perceived as rendered: one part is seen as concave and the other as convex.
- Under Orthographic projection, we observed One Bump - One Crater stimuli were perceived as Both Bumps and non-rigidly "Folding". (See Exp. 1)
- Under Perspective projection, the One Bump – One Crater stimuli were seen as Both Bumps with the Crater part perceived as a Bump "Bending" non-rigidly. (See Exp. 2)

Experiments

We investigated the competition between priors for Convexity and Rigidity.

- To manipulate convexity, stimuli had parts that were either Half Ellipsoids or Bivariate Gaussians (ellipsoids more convex).
- We manipulated non-rigidity via the angular range of rotation of the surface: larger ranges of rotation lead to greater deviations from rigidity in the non-rigid percepts.

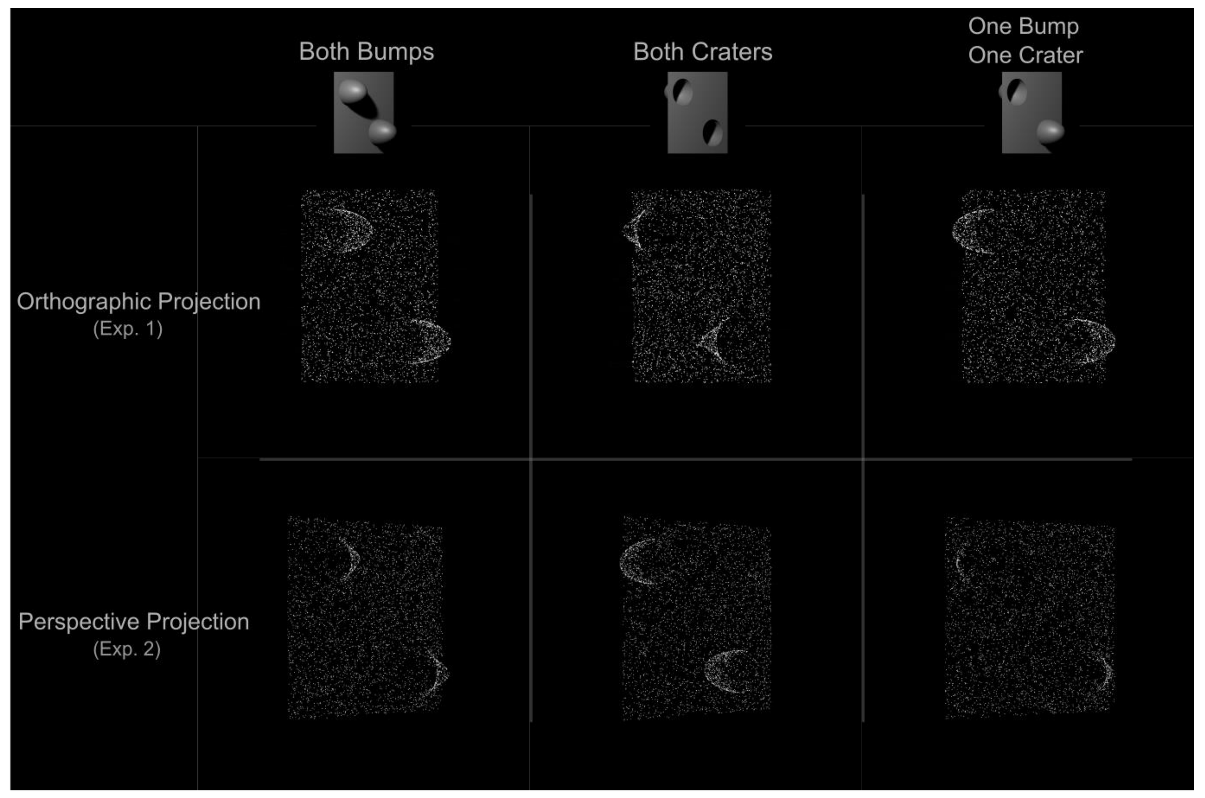
References: **[1] Ullman, S. (1979).** The interpretation of structure from motion. *Proceedings of the Royal Society of London. Series B. Biological Sciences*, *203*(1153), 405-426. **[2] Jain, A., & Zaidi, Q. (2011).** Discerning nonrigid 3D shapes from motion cues. *Proceedings of the National Academy of Sciences*, *108*(4), 1663-1668. **[3] Todd, J. T. (1984).** The perception of three-dimensional structure from rigid and nonrigid motion. *Perception & Psychophysics*, *36*, 97-103. **[4] Domini, F., Caudek, C., & Proffitt, D. R. (1997).** Misperceptions of angular velocities influence the perception of rigidity in the kinetic depth effect. *Journal of experimental psychology: human perception and performance*, *23*(4), 1111.

We ran two experiments:

- Experiment 1 presented stimuli under **orthographic** projection.
- Experiment 2 presented stimuli under **perspective** projection.
- While the surface geometries in both studies were identical, the difference in projection lead to very different non-rigid interpretations.

Stimuli

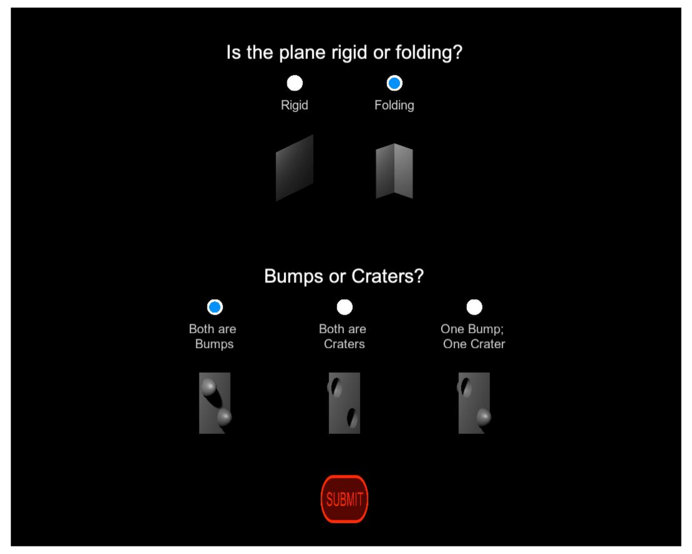
- A square plane with protrusions in the upper-left and bottom-right quadrants.
- Each part could be a convex "Bump" or concave "Crater".
- Parts were either Half Ellipsoids or Bivariate Gaussians
- Surfaces rendered with a transparent, random-dot texture.
- Surfaces begin with the square plane frontoparallel. Rotate back and forth about its central vertical axis.
- Motion sequence was presented for 6 seconds.



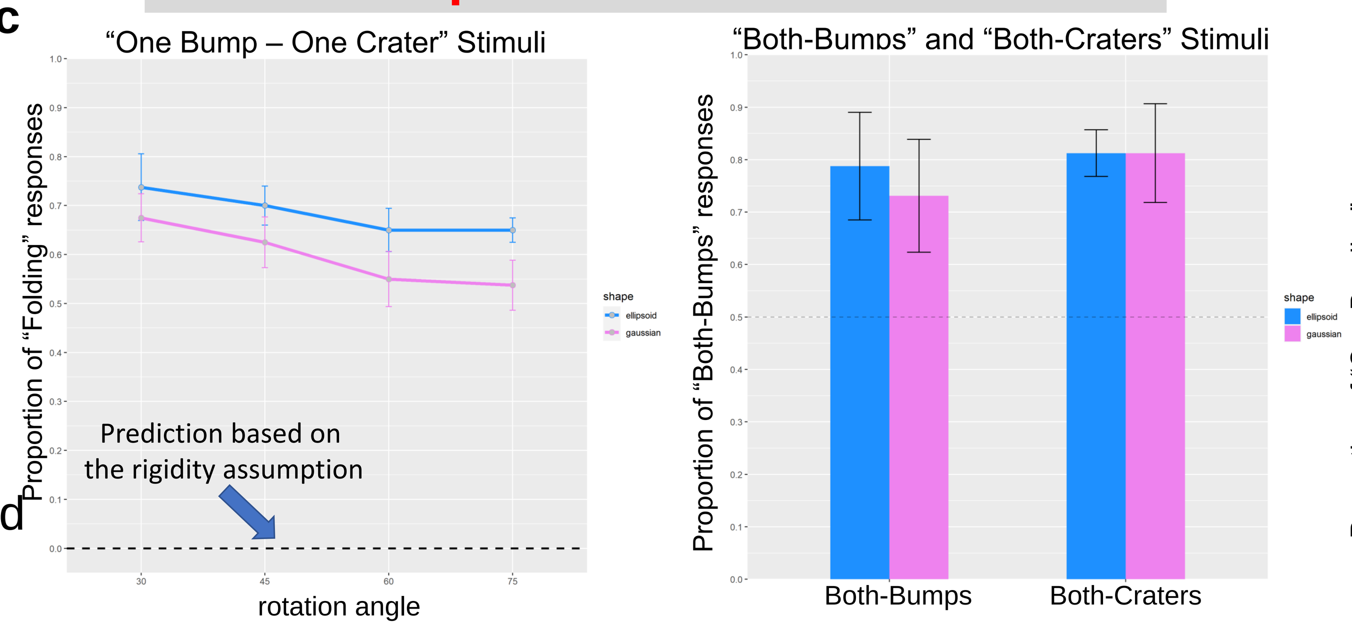
(Gray 3D models not shown to subjects.)

Experiment 1: Orthographic Projection

- We investigated the frequency of the non-rigid "Folding" percept as a function of two variables:
  - 4 ranges of rotation: +/- 30°, 45°, 60°, 75°
  - Parts were either Half Ellipsoids or Gaussians.
- Subjects responded whether:
  a) the surface was Rigid or Folding and,
  b) The parts were Both Bumps, Both Craters, or One Bump and One Crater



Experiment 1 Results



One Bump – One Crater Stimuli (left plot)

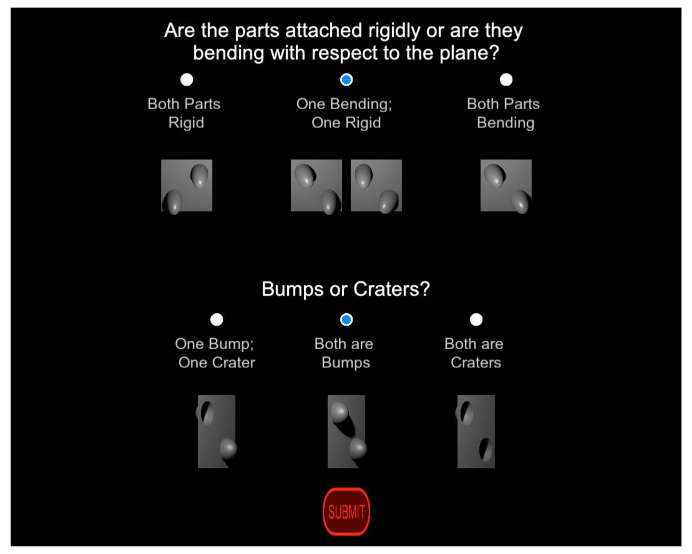
- Perceived as non-rigidly "folding" on a majority of trials. (Note that the prediction for the rigidity assumption is at 0).
- Proportion of non-rigid responses were significantly higher for the half ellipsoids (more convex) than for Gaussian parts. [logistic regression: $\chi^2(1) = 5.57, p < 0.05$)]
- The proportion of non-rigid responses decreased as the range of rotation increased (deviation from rigidity increases). [logistic regression: $\chi^2(1) = 5.33, p < 0.05$)]

Both-Bumps and Both-Craters Stimuli (right plot)

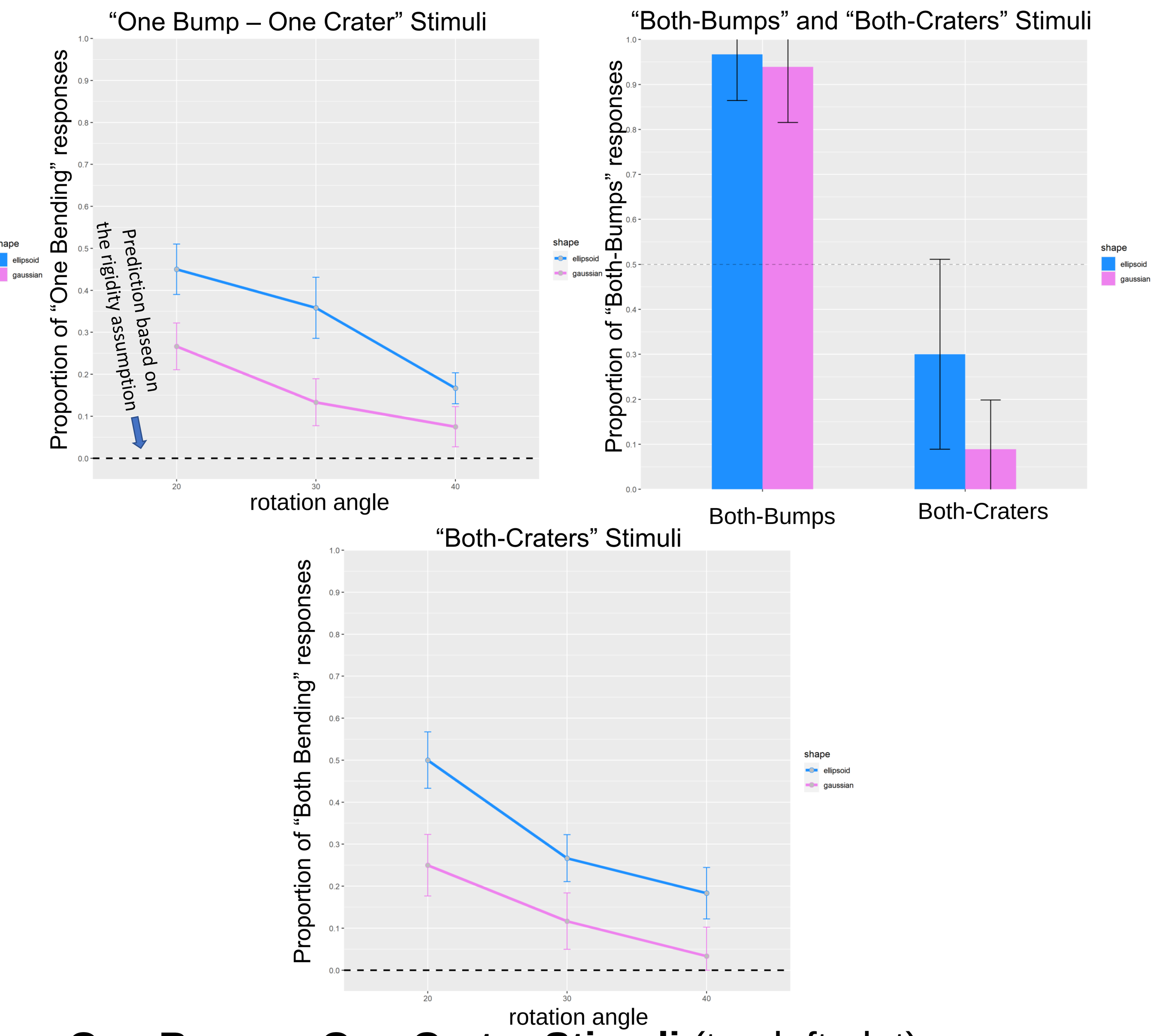
- Both types of stimuli were perceived as Both Bumps on the majority of trials (demonstrating a convexity bias).
- Under Orthographic projection both types of stimuli are projectively equivalent up to a reversal in slant direction.

Experiment 2: Perspective Projection

- We investigated the frequency of the non-rigid "Bending" percepts as a function of two variables:
  - 3 ranges of rotation: +/- 20°, 30°, 40°
  - Parts were either Half Ellipsoids or Gaussians.
- Subjects responded whether:
  a) The parts were Rigid, One Bending-One Rigid, or Both Bending and,
  b) The parts were Both Bumps, Both Craters, or One Bump and One Crater



Experiment 2 Results



One Bump – One Crater Stimuli (top left plot)

- Perceived as having one part non-rigidly bending while the other is rigid.
- Again, the proportion of non-rigid responses is significantly higher for the more convex shape [logistic regression: $\chi^2(1) = 37.80, p < 0.05$] and decreases as angle of rotation increases [logistic regression $\chi^2(1) = 27.73, p < 0.05$].

Both-Bumps and Both-Craters Stimuli (top right plot)

- Perspective has greatly reduced the proportion of "Both Bumps" responses to Both-Craters stimuli.

Both-Craters Stimuli (bottom plot)

- Still perceived as having both parts "Bending" non-rigidly for a significant proportion of trials (despite both perspective and the rigidity bias being against this interpretation).

Discussion

- Both experiments demonstrate that when convexity and the rigid-motion bias compete against each other, convexity wins. (Subjects' percepts favored convexity even when it required seeing the surface as non-rigid).
- While introducing perspective (Exp. 2) brought down the proportion of non-rigid responses, all curves remained significantly higher than zero (the rigidity-based prediction).
- The results of Exp. 2 show that convexity can win over the combined effect of perspective and the rigid-motion bias.
- The results of both experiments point to the need for investigating various prior constraints used in the interpretation of SFM beyond just rigidity – and especially how these priors interact with each other.