Object Rigidity: Competition and cooperation between motion-energy and feature-tracking mechanisms and shape-based priors

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Why do objects appear rigid when projected retinal images are deformed non-rigidly by object or observer motion? We used rotating rigid objects that can appear rigid or non-rigid to test whether tracking of salient features counteracts nonrigidity.

When two circular rings are rigidly linked at an angle and rotated (Fig. 1a), they appear wobbling and not linked rigidly. Movies and window displays have used this illusion but there is no published explanation. These percepts contradict the conventional rigidity assumption. Two alternative forced choices between the link being rigidly connected or not, showed a preponderance of non-rigid percepts at moderate speeds (6.0 deg/sec). Responses of arrays of motion energy units show that despite the object being physically rigid the pre-dominant motion energy vectors are perpendicular to the contours of the rings instead of in the rotation direction. We trained a convolutional neural network on 9000 motion flows to distinguish between motion flow patterns for wobbling and rotation. Flows from MT component cells to the trained CNN gave a high probability of wobbling.

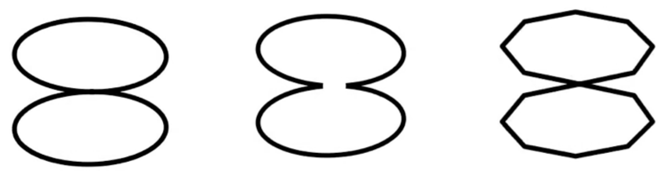

Fig. 1

At slow speeds (0.6 deg/sec) observers reported rigid rotation, so we tested whether feature tracking can promote rigidity by adding salient features. When the link was painted or replaced by a gap, or if the rings were polygons with vertices (Fig. 1b and c), the rings appeared rigidly rotating at 6.0 deg/sec. Phenomenologically, the motion of painted segments, gaps, or vertices provides cues for rotation and against wobbling. These salient features can be tracked by arrays of MT pattern-motion cells or by explicit feature-tracking. The CNN gave high probabilities of rotation for motion flows from feature tracking. However, at high speeds (60 deg/sec), all configurations appeared non-rigid. Salient feature-tracking thus contributes to rigidity at slow and moderate speeds, but not at high speeds. Combinations of CNN outputs from motion energy and feature tracking did not fully explain differences in percepts between circular and polygonal rings because they generate similar motion energy (R^2=0.64). We found that circular rings give an illusion of spinning around their own center despite lack of physical evidence, but the illusion is suppressed by vertices, gaps and painted segments, suggesting that a powerful prior for rolling may depend on rotational symmetry or jaggedness of the shape. The two factors together predicted rolling frequency with R^2 = 0.90, 0.94 & 0.79 for slow, medium, and fast speeds. The addition of this shape-based prior to the CNN output, leads to an R^2=0.95, which suggests that we have almost completely accounted for the most important factors.