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# A Feature-Based Model of Visually Perceiving Deformable Objects

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Visually inferring the properties of deformable objects is challenging, because the observable behavior of such objects depends not only on their internal properties, such as stiffness and elasticity, but also on the external forces applied to them. How does the brain disentangle these different factors when visually estimating the properties of non-rigid objects?

We simulated and rendered five types of animations in which a deformable target object interacts with different rigid objects (see **Figure 1**). Besides this manipulation of the external factors, we varied the *stiffness* (soft vs. hard) and *elasticity* of the target, i.e. whether the object returns to its original shape after a deformation (elastic) or not (plastic), and asked observers to judge these internal properties. Plastic objects were perceived softer than elastic objects of the same stiffness. Overall, however, the responses were in accordance with the simulated stiffness and elasticity see **Figure 1**.

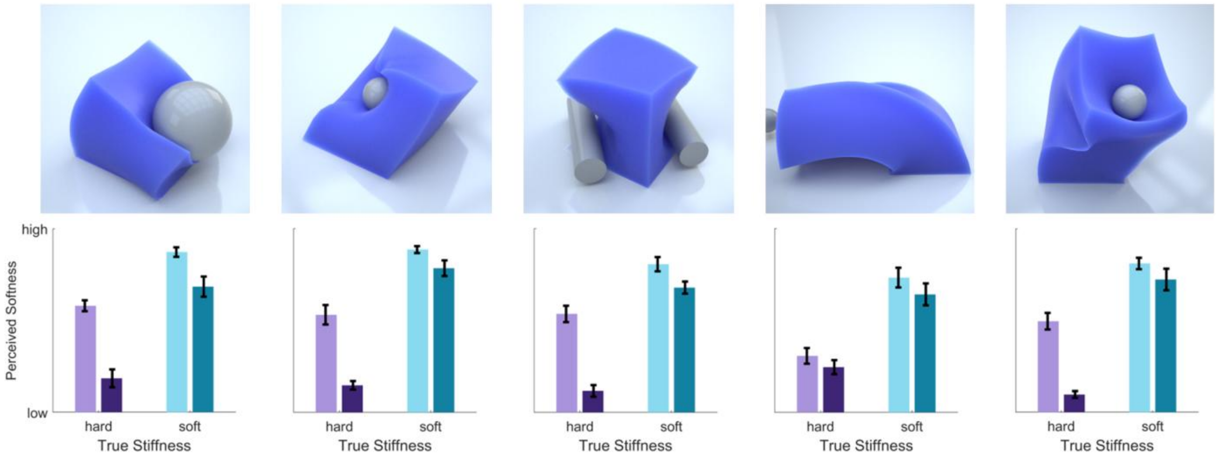



*Figure 1. Top row shows snapshots of the target objects being deformed by rigid objects. Below are corresponding mean softness ratings.*

This is a striking achievement because the visual input from *different* materials presented in the same scene layout is highly similar, whereas there is low similarity between *identical* materials interacting with different forces. **Figure 2** shows the representation of the stimuli in the shape-similarity space, i.e. the raw input to the visual system. Stimulus similarity is strongly dominated by the external factors with very little effect of the intrinsic material properties. To overcome this, we suggest that instead of relying on pure shape similarity, the visual system might use the characteristic *behavior* of non-rigid objects in order to judge stiffness and elasticity, i.e. the way they deform, bend or wobble back and forth.

We measured seven different deformation features on the underlying 3D meshes (see **Figure 3**). Remarkably, in this seven-dimensional feature space our stimuli are organized by their internal properties, not by superficial similarities such as their size, see **Figure 4**. Combination of the features in a linear regression model predicts perception very well, see **Figure 5**. To test the contribution of individual features and the generalizability of our model, we simulated a much larger data set of more than 200,000 animations in which we varied the shape of the target, its material properties, the scene layout and the type and amount of external force. Our results suggest that the brain represents non-rigid objects in a multidimensional feature space, which allows constant estimates of their internal properties across a large variety of contexts.

*Figure 2. Representation of stimuli in the shape-similarity space. Shown are the first 2 principle components from a PCA on the 3D position of 176 corresponding points in the meshes of all objects in all frames.*

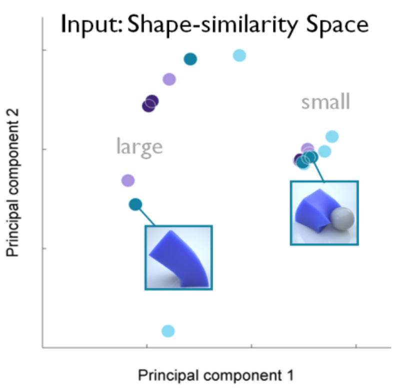
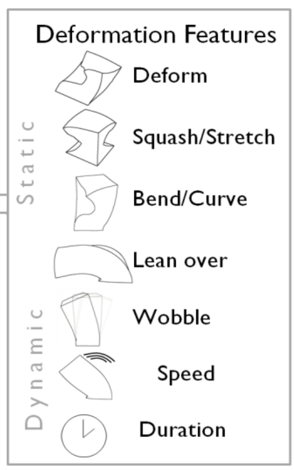



*Figure 3. Deformation features. Four static and three dynamic deformation features were calculated for all objects.*



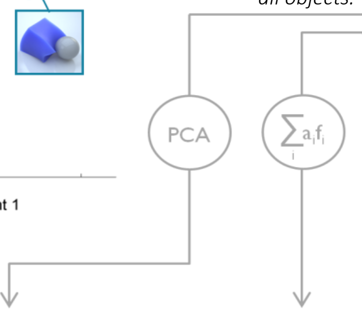
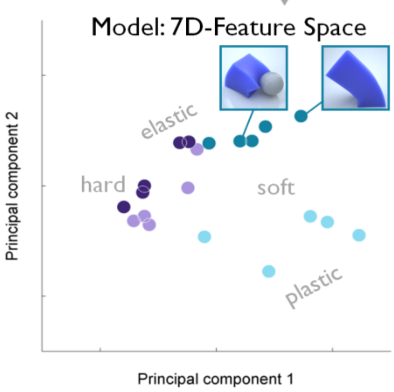




*Figure 4. Representation of the stimuli in the 7D-feature space (first two PCs from PCA). Stimuli are reorganized by their internal properties, e.g. the example images are now much closer to each other.*



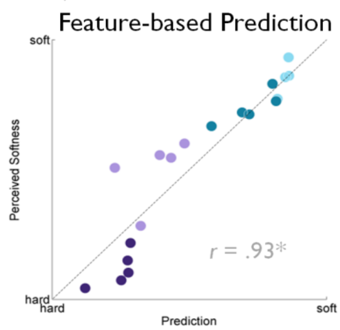




*Figure 5. Feature-based prediction of perceived softness.*