Effects of optical material properties on detection of deformation of non-rigid rotating objects

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When a three-dimensional object undergoes changes in position, orientation or surface geometry the image motion (optical flow) changes too. This change is influenced greatly by the object's optical material and the illumination conditions. This is because different image components, such as surface textures, occluding contours, shading, highlights (for glossy materials), and internal reflections (for transparent materials) can each interact in different and/or unique ways to changes in the surface orientation, viewing direction, illumination, etc. In other words, a specific informative image cue indicating a deformation in one material might not be present or informative for another material.

This material dependency of image motion makes the perception of dynamic realistic 3D objects a challenging task for the human visual system.

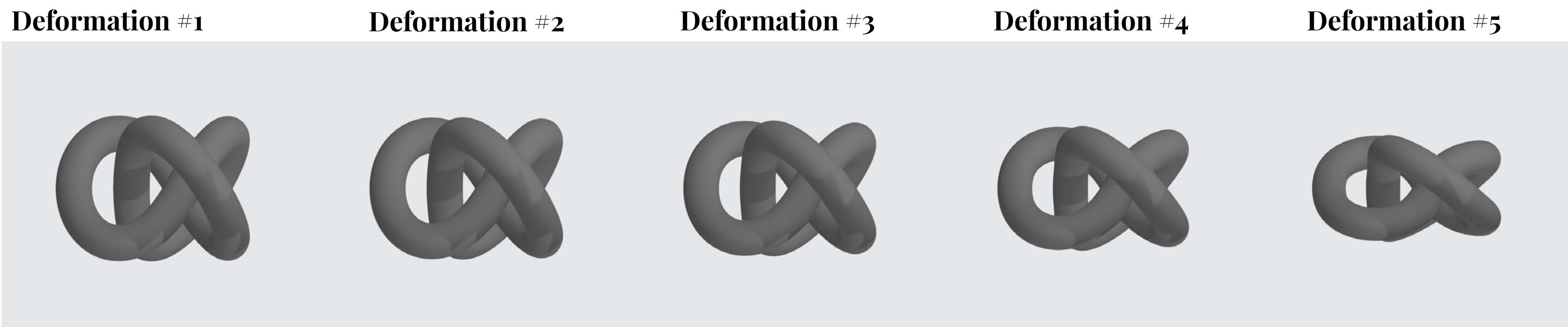
The Challenge

The visual image is strongly influenced by material identity and illumination. As a result, correct detection or estimation of deformation, i.e., dynamic changes in the shape of an object, can be a challenging visual task.
Here we try to study and test the human ability to perceive non-rigid deformations across a variety of materials and illuminations.

Stimuli

We used three-dimensional infinite knot stimuli which were rendered with Maxwell Renderer. Sequences of 120 frames were generated, in which the knot stimulus would slowly deform as the result of an inwards pulling force. The intensity of the force varied across the deformation condition as one of 5 logarithmically increasing steps of in-wards pulling force. See figure 1 for examples of the maximum deformation for each intensity. Deformation was simulated using RealFlow. The stimuli start deforming after frame 0, reach a peak at frame 30, and return to the non-deformed shape at frame 60, from which it starts to deform again towards a peak at frame 90, etc.

Deformation #1 | **Deformation #2** | **Deformation #3** | **Deformation #4** | **Deformation #5**



From left to right, increasing maximum deformation. In a sequence, the stimuli would deform from a not deformed state to this maximum deformed state. Not pictured here is the default non-deformed state which is perceptually identical to the left-most image.

Stimuli- illumination

The stimuli objects were rendered under one of three light conditions.

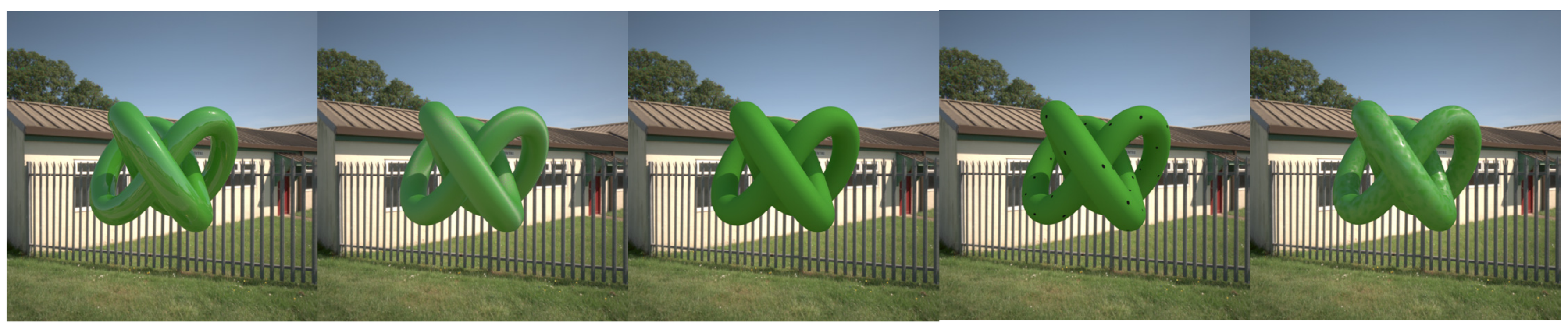
Indoors

Outdoor, overcast

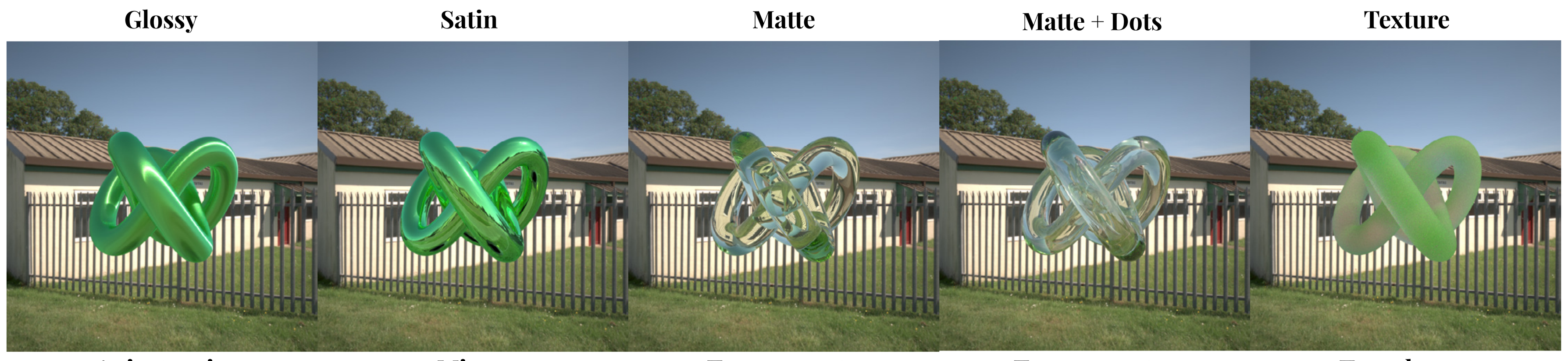
Outdoors, sunny

Stimuli- material

Stimuli were rendered with one of ten materials.



Glossy | **Satin** | **Matte** | **Matte + Dots** | **Texture**



Anisotropic | **Mirror** | **Transparent 1** | **Transparent 2** | **Translucent**

Conclusions

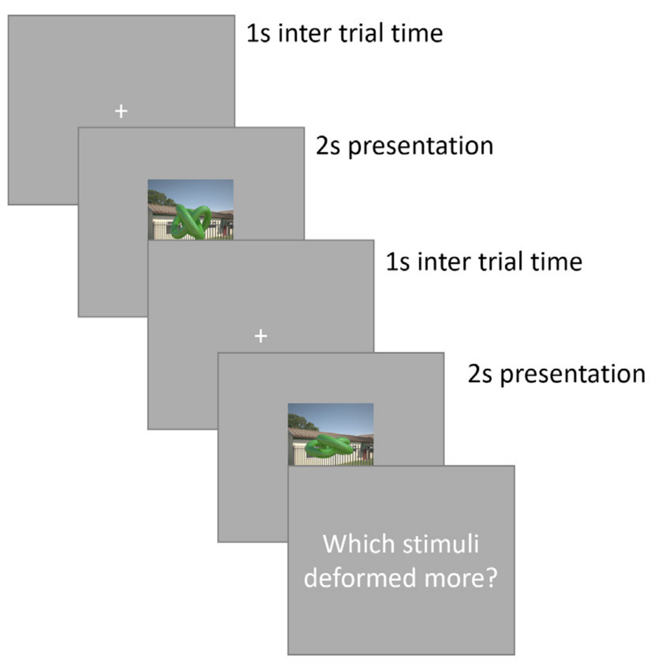
These results suggest that the visual system can robustly interpret the deformation of a moving 3D object despite large variations in the optical flow caused by changing optical conditions.

We appear better capable of discounting the effects of illumination for deformation detection relative to our ability of discounting the effects of material.

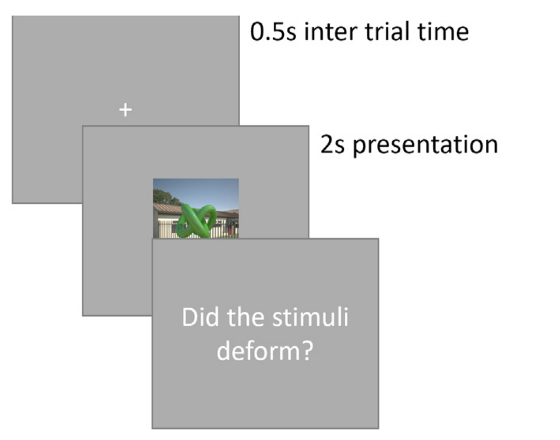
Methods

We conducted one experiment (n=7) with two tasks. Participants would perform both tasks within a single session, with the order of the tasks randomized between participants. In one task, participants would perform a 2-ifc task in which they were asked to judge which of the two stimuli deformed more. In the other task participants performed a detection task in which participants had to indicate whether they detected deformation or not.

First task: 2-interval forced choice



Second task: Yes-no experiment



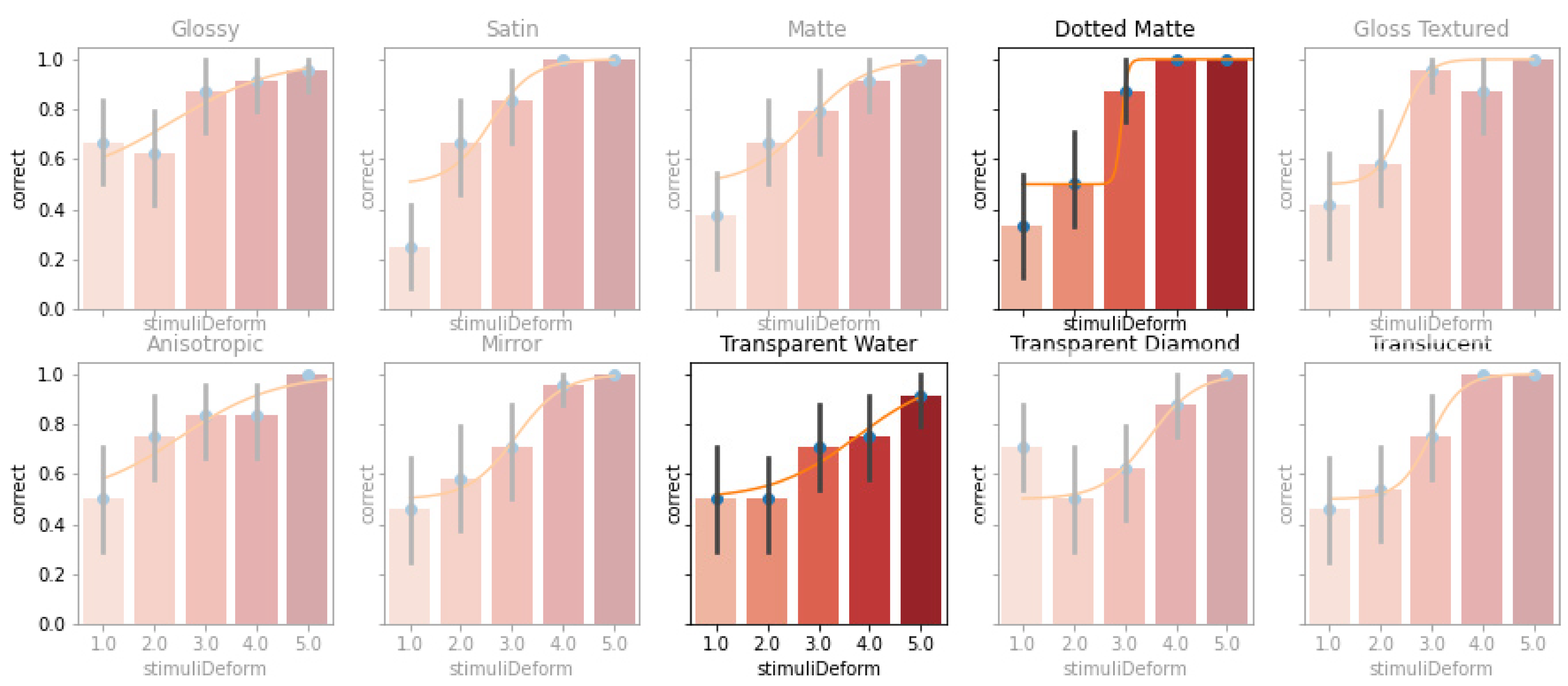
Results

In this study, we tested the human visual systems' ability to discriminate and detect non-rigid deformations. Stimuli varied on deformation, material and light scenes.

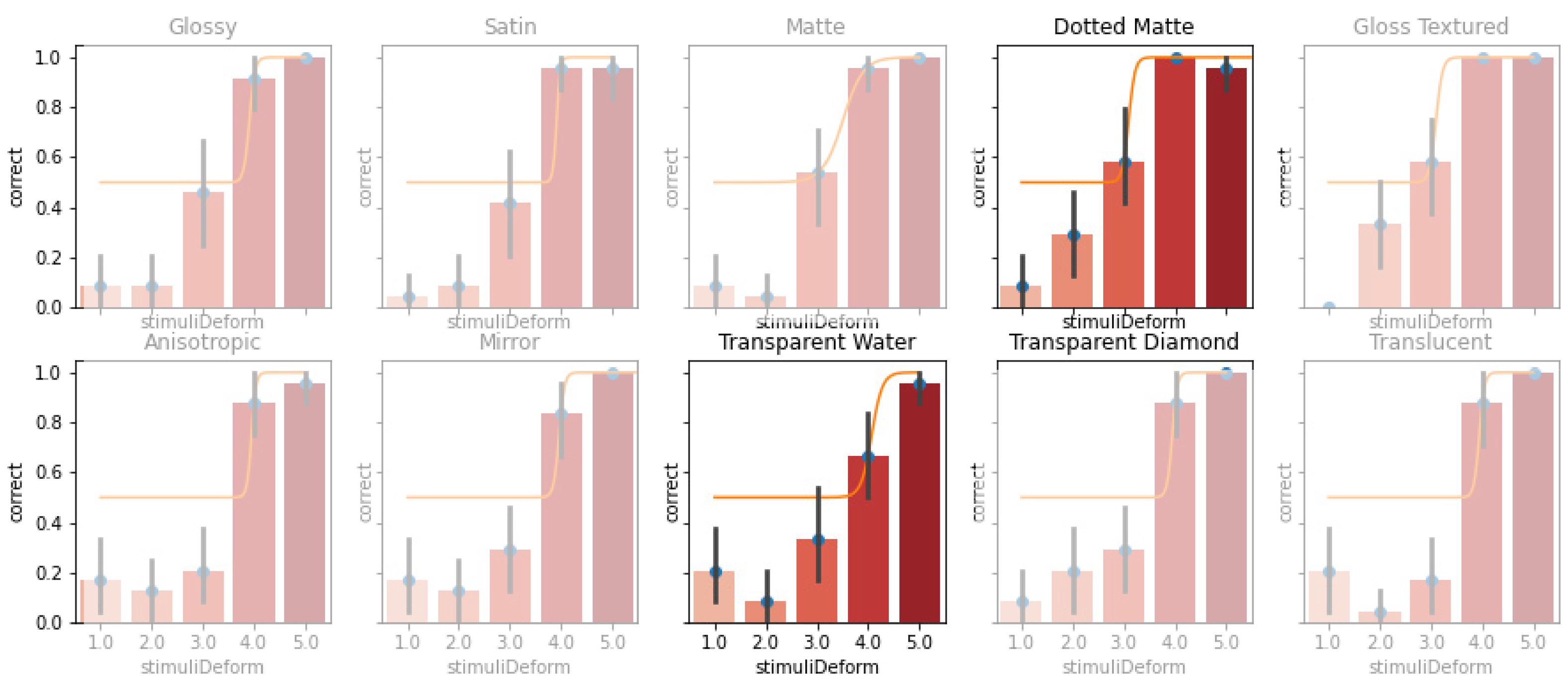
We found the largest performance differences in deformation perception across participants between the optically more complex transparent stimuli and the simpler textured matte stimuli.

A GLM (logit) regression model shows a simple main effect of stimuli deformation, $z = 13.8$, $p<.000$, CI95%[0.77, 1.025], and a moderate main effect of material, $z=-2.9$, $p=.004$, CI95%[-0.128, -0.024], but no main effect of illumination.

Percentage correct for 2IFC per material



Percentage responded deformation detected for yes-no experiment per material



Acknowledgment

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