How does motion affect material perception of deformable objects?

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Abstract

Humans are very efficient at visually estimating material properties from dynamic scenes. Here we ask whether, and how, dynamic information can affect the perception of mechanical properties of cloth. Experiment 1 found that material categories (e.g., Is the cloth silk or felt?) significantly influence the estimation of the stiffness of cloth in both the image and video condition. However, this effect is largely decreased in the video condition. In Experiment 2, we quantified the motion information using a new visual cue, speed coherency, which is calculated from the spatial-temporal displacement within every two consecutive frames. We provide experimental evidence to show that manipulating the speed coherency can directly alter the impression of objects' stiffness. In sum, we demonstrate that dynamic information can partially discount the effect caused by the optical properties. Moreover, dynamic information alone influences the perception of mechanical properties.

Keywords: dynamic information, material perception

Introduction

Visually estimating mechanical properties (e.g., stiffness) of deformable objects (e.g., cloth) is important for planning successful actions. However, this task is challenging because both optical properties (e.g., textures, gloss, and transparency) and intrinsic mechanical properties will affect their appearances. The deformable objects with identical intrinsic mechanical properties might look/move differently if they have different optical properties, or if they are under different applied forces. On the other hand, objects with different mechanical properties might appear similar if the external force and optical information are appropriated configured. The challenge of visually estimating the mechanical properties has inspired some psychophysical work to examine how well humans use various static and motion cues to achieve this.

Previous research shows that dynamic information affects the perception of surface gloss of rigid objects(Doerschner et al., 2011; Dövencioğlu, Ben-Shahar, Barla, & Doerschner, 2017; Marlow & Anderson, 2016). Studies on the perception of deformable objects suggest that the visual system uses both dynamic and static cues to estimate material properties, and visual estimation of mechanical properties is more accurate with videos in comparison with images (Kawabe, Maruya, Fleming, & Nishida, 2015; Bi, Jin, Nienborg, & Xiao, 2018; Bouman, Xiao, Battaglia, & Freeman, 2013; Paulun, Schmidt, van Assen, & Fleming, 2017; Van Assen, Barla, & Fleming, 2018; Schmid & Doerschner, 2018; Schmidt, Paulun, van Assen, & Fleming, 2017). We have previously found that statistics of two-frame optical flow is highly correlated with the perceived stiffness (Bi & Xiao, 2016). Moreover, image features from fifteen-frame dense motion trajectory can successfully predict the perceptual scale of stiffness (Bi et al., 2018). However, as Figure 1 shows, optical flow and dense trajectory are not only influenced by the dynamic information such as spatial displacement, but also by optical properties such as glossiness. Little is known how important dynamic information could influence material perception in comparison to optical properties. Moreover, optical properties might have a top-down influence on the perception of stiffness via high-level associations. For example, textures highly influence how we categorize the cloth (e.g. jeans has a specific woven pattern and color).

In this paper, we use cloth as the model because it is one of the most common types of deformable objects. The contribution of this paper is two-folded. First, we find that motion can affect the perception of stiffness by discounting the top-down influence of optical properties. We believe the top-down influence, characterized as the material category, highly affects the perception of material properties of cloth. Second, we aim to demonstrate that motion information alone, without optical information, can influence the perception of the stiffness of cloth. Particularly, we find that manipulating speed coherency, a new motion feature, can influence the stiffness perception.

Experiment 1

We aim to test whether the top-down process induced by optical properties can affect the perception of stiffness and whether motion can discount this effect. Six participants finished a multi-choice task (Figure 2 A, upper panel) where they adjusted the stiffness of a reference cloth (right) to match that of the target cloth (left). The adjustment was done by selecting a cloth from a set of pre-rendered videos (Figure 2 A,

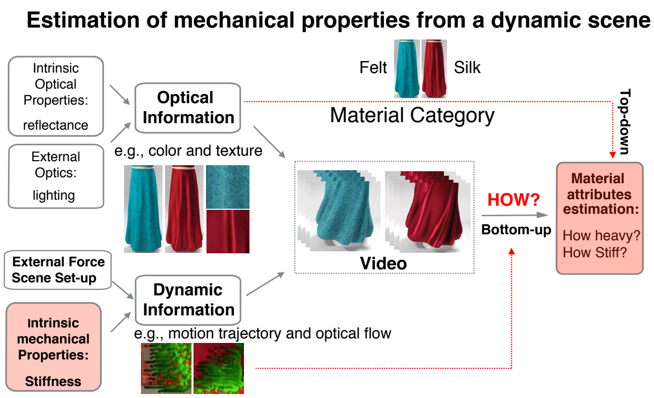

Figure 1: Both static appearance and dynamic information are important in estimating mechanical properties from a dynamic scene. The static appearance, such as texture and color, is related to the intrinsic optical properties. By contrast, the dynamic information, such as motion trajectory and spatial displacement, is determined by the intrinsic mechanical properties. The estimation of mechanical properties includes both the top-down and bottom-up process. Static appearance can induce the material categorical judgment (e.g., is this cloth is silk or felt?), which greatly influence the top-down process. In the bottom-up process, the estimation mainly depends on the images features which contain both the static and dynamic information. Two questions remain unclear. First, whether dynamic information alone can affect the estimation of mechanical properties. Second, whether dynamic information can discount the influence of optical information and alter the perception.

lower panel). They finished the task in both the video condition where both the reference and target cloth were shown in videos, and in the image condition where the reference cloth was displayed dynamically as video but the target cloth was displayed as image.

The videos were rendered in Blender 2.7.6. The target cloth was rendered with stiffness value $\{0.01, 0.1, 1, 10, 100\}$, mass value $\{0.1, 0.7\}$, four distinctive fabric categories (Figure 2 A, lower panel), and two dynamic scenes. The wind scene contained a piece of hanging cloth moving under oscillating wind forces (see Figure 2 A, upper panel, right). The ball scene contained a rolling ball colliding with the hanging cloth (see Figure 2 A, upper panel, left). The reference cloth was rendered with stiffness value $\{0.005, 0.01, 0.1, 0.5, 1, 5, 10, 25, 100, 300\}$, mass value 0.3, and under the wind scene set-up. Each participant finished 240 trials in both of the image and video conditions (5 stiffness values $\times$ 2 mass values $\times$ 4 material categories $\times$ 2 scene set-ups $\times$ 3 repetitions).

Results

Figure 2B shows the results of Experiment 1. First, the material category has a significant effect on the perception of stiffness in both the image (Figure 2B1) and video (Figure 2 B2) condition such that the cotton is consistently rated to be stiffer than both the red gauze and brocade. However, differences in the rating between different material categories are smaller in the video condition than in the image condition, suggesting that the effect of the material category largely decreases in the video condition. Second, Figure 2B shows that the lines for the video condition are steeper than those for the image condition, suggesting that participants show higher sensitivity to different stiffness values in the video condition. Experiment 1 demonstrates that motion can weaken the effect of material categories on the perception of stiffness. In addition, participants show enhanced the discriminative sensitivity to different stiffness values in the video condition, which is consistent with previous findings (Bi et al., 2018).

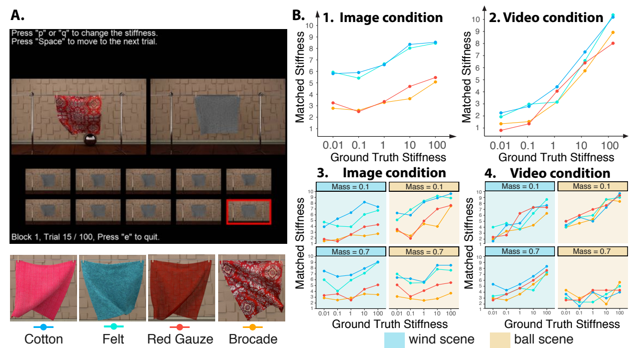

Figure 2: Motion can partially discount the effect of optical properties and lead to higher discriminative sensitivity. (A) Upper panel: the experimental interface. Participants adjust the stiffness of the reference cloth (right) to match that of the target cloth (left) by selecting one of the reference videos. The participants can see the whole range of stiffness values from the small reference videos (rows below) and when they select one of them, it will show up at the position of the reference (right). Lower panel: the target cloth is rendered with four different material categories (from left to right: Cotton, Felt, Red Gauze, and Brocade). (B) Perceptual results. X-axis indicates the stiffness value of the target cloth. Y-axis refers to the adjusted stiffness value of the reference cloth. Different colors indicate different material categories. (B1) The perceived stiffness is highly affected by material category in the image condition. (B2) The effect of material categories largely decreases in the video condition. (B3 and B4) Same as B1 and B2, but the results are grouped by two mass values and two scenes.

Experiment 2

The goal of Experiment 2 is to answer whether dynamic information alone can influence the estimation of stiffness. In particular, we propose that the speed coherency, a new dynamic cue, can influence the stiffness perception of cloth. To remove the effect of optical properties, we use a dynamic dot stimulus (see Figure 3 A), and therefore motion is created by displacement of dots. The speed is defined as the spatial displacement within every two consecutive frames. The speed is more coherent when more dots move with similar speed. By contrast, the speed coherency is low when the speed of each dot differs a lot. We hypothesize that increasing the speed coherency will make the cloth appear stiffer.

Method

The 3D dynamic dot stimuli video was created using the 3D mesh output from Blender. Based on this original stimuli, we then generated new dot stimuli by the methods shown in Figure 3 A. In particular, we manipulated the speed of each dot such that we held the frame update rate constant while varying the spatial displacement of each dot.

Based on the original video (bending stiffness = 0.1), we created five new 3D dynamic dot stimuli with α value {0.2, 0.4, 0.6, 1.0, 1.2}. We conducted an MLDS (maximum likelihood difference scaling) experiments with triads to measure the perceptual scale of these videos (Maloney & Yang, 2003). At each trial, participants watched three different 3D dynamic dot stimuli. Their task was to judge which video contained materials that appeared to be more different in stiffness.

Results

Figure 3 B plots the estimated perceptual scale averaged across all the three participants, which were estimated by MLDS using the GLM (generalized linear model) implementation (McCullagh, 1984). Results show that the perceived stiffness decreases as the α value increases in a linear fashion, suggesting that merely manipulating the speed coherency defined by the function that we described can influence the perceived stiffness reported by the participants.

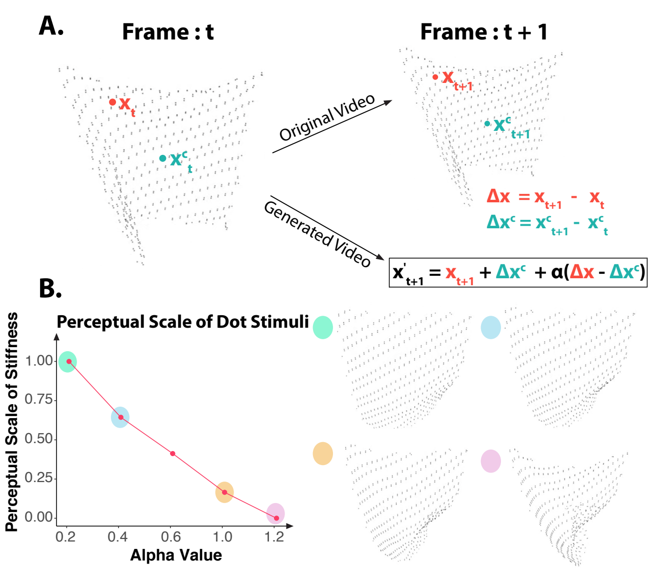

Figure 3: Changing speed coherency can influence perceived stiffness. (A) Given any frame t, the coordination of the mass center of the 3D dynamic dot stimuli is defined as x_t^c. x_t refers to the coordination of the interest point. The movement of the interest point in frame (t, t+1) is defined as $\Delta x = x_{t+1} - x_t$. Similarly, the movement of the mass center of the dot stimuli is defined as $\Delta x^c = x_{t+1}^c - x_t^c$. Therefore, the new coordination of the interest point at frame (t+1) can be calculated by $x_t^{'} = x_{t+1} + \Delta x^c + \alpha\ (\Delta x - \Delta x^c)$, where α is the parameter that determines the speed coherency. $\alpha < 1$ decreases the speed coherency, and by our hypothesis, will make the cloth look stiffer. Vice versa for $\alpha > 1$. (B) Perceptual scale of the 3D dynamic dot stimuli. Perceived stiffness decreases as the α value increases in a linear fashion.

Conclusion

This paper discovers that the perception of stiffness is mainly affected by the material categorization when the stimuli are displayed as images. When shown as videos, dynamic information can partially discount the effect of material categories on the perception of intrinsic mechanical properties. Consistent with previous findings, we also find that the sensitivity to different stiffness values is enhanced in the video condition than the image condition. More importantly, we propose a new way to isolate and quantify the dynamic information, and show that directly manipulating the dynamic information can alter the perceived mechanical properties.

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