Vision Research 109 (2015) 201–208

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Material perception of a kinetic illusory object with amplitude and frequency changes in oscillated inducer motion

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ARTICLE INFO

Article history:
Received 17 June 2014
Received in revised form 26 September 2014
Available online 24 December 2014

Keywords:
Material perception
Motion perception
Illusory contour

ABSTRACT

The magnitude of the phase difference between inducers' oscillation of a kinetic illusory surface influences visual material impressions (Masuda et al., 2013). For example, impressions of bending or waving motions on a surface tend to occur at a 30- or 90-deg. phase difference, respectively. Here, we elucidate whether amplitude and frequency changes in an inducer's oscillation influence the visual impressions of an illusory surface's hardness, elasticity, and viscosity. Nine participants were asked to use an analog scale to judge their visual impressions relative to a standard pattern with no damping and no frequency change for each phase difference.

Results revealed that hardness ratings were greater when amplitude decayed with time only in the 30-deg. phase difference. Elasticity ratings were greater when the frequency of oscillation had a large increase in the 90-deg. phase difference. In the 30-deg. phase difference, similar tendencies were only observed with no damping and ample damping. Viscosity ratings were greater when the frequency of oscillation decreased in both phase differences and when the amplitude decayed with time in the 30-deg. phase difference.

These findings suggest that amplitude and frequency changes in an inducer's oscillation are significant factors for material perception derived from motion.

1. Introduction

Visual motion provides rich information for material perception. Several reports have indicated that observers perceive various material properties of objects, such as mass, elasticity, rigidity and hardness, based on visual motion (e.g., Masuda et al., 2011b; Todd & Warren, 1982; Warren, Kim, & Husney, 1987). Some studies have reported on some types of motion related to material perception. For example, many studies have reported that observers can perceive the relative mass of colliding objects and the acting forces in a visual collision event (e.g., Todd & Warren, 1982) and observers perceive a moving object's elasticity based on velocity changes around its collision with the surface or from the amplitude of its bounce (Warren et al., 1987). Johansson (1964) demonstrated that the motion of a shape continuously changing from a square to a rectangle was perceived as either rigidly rotating in depth or non-rigidly folding or bending in depth. Additionally, observers tended to perceive such deformation as rotation, bending, and stretching, in decreasing order of frequency (Jansson & Johansson, 1973). Other studies reported that observers could perceive the bending motion from point lights (Jansson, 1977), and the frequency of a perceived bending motion derived from quad-angular deformation varied with the degree of phase lag between the motion of corners (Jansson & Runeson, 1977). Norman et al. (2007) demonstrated that observers could discriminate elasticity from a simulated bending motion even with varying orientation in depth, although the projected velocity of bending varied with the rotation of bending in depth.

Recently, Masuda et al. (2013) demonstrated that kinetic illusory objects were perceived with various material impressions. In this previous study, the subjective contours of the illusory object were composed of four sets of three concentric circles, and the constructional lines of a quarter segment of each set of circles were painted blue to cause the perception of a faint bluish color within a square region (Fig. 1a). When the phase differences between the oscillating motion of the top two and bottom two vertical boundaries were controlled (Fig. 1b and c), material impressions could be systematically changed by manipulating the phase difference between the inducers' oscillations (Masuda et al., 2013). The results showed that a rigid object tended to be perceived under conditions without a phase difference (0- and 180-deg. phase difference conditions), a bending object tended to be perceived under the 30-deg. phase difference conditions, and a waving object

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http://dx.doi.org/10.1016/j.visres.2014.11.019
0042-6989/

tended to be perceived under the 90-deg. phase difference conditions. In nature, actual rigid swinging, bending, and waving motions occur with undeformable rigid, high-elasticity, and low-elasticity (or liquid-like) materials, respectively. Therefore, the differentiation between motion impressions might be determined by an observer's material perceptions of an illusory object.

The phenomena Masuda et al. (2013) reported implies the potential link between the determining factor of material perception derived from visual motion and the mechanical behavior of an object which varies with the type of material. It can be assumed that the effect of phase difference on material perception is related to the viscoelastic stress–strain relationship obvious in the mechanical behavior of a material which has both viscous and elastic physical characteristics during deformation. The proportion of these characteristics is determined by the phase lag (phase difference) between stress and strain, which is between 0 and 90 deg. This difference declines to 0 deg. as the elasticity of the object increases (solid-like material) and reaches 90 deg. as the viscosity of the object increases (liquid-like material). Purely elastic materials have stress and strain characteristics in phase (0 deg. phase difference) and purely viscous materials have a 90-deg. phase difference between stress and strain. Viscosity is the resistance to flow and strain with time when a stress is applied. Typically, a high viscosity object is thick or sticky. Elasticity is the return of materials to their original shape after stress is released. Viscoelastic materials have elements of both properties. To summarize, in nature a phase lag results from differences in the type of materials that an object is composed of. Masuda et al. (2013) showed that the changing of a motion impression of a material, which is caused by a change in phase difference, can be explained by temporal differences in the motion of a viscoelastic object in nature.

Thus we can hypothesize that material perception from visual motion is derived in a manner analogous to solving physical equations with variables such as phase difference and amplitude change in frequency of oscillation.

Here, we can expect that the amplitude and frequency changes in the pendular motions of the stimuli Masuda et al. used are related to material perception from visual motion because, as with phase differences, they can change with the physical properties of materials. Meanwhile, deformation of contours caused by phase difference has many potential variations, such as linear or curved shaping or varied numbers of vertices, which could influence material ratings. Using an illusory figure with kinetic subjective contours allowed us to investigate the factors of phase difference, frequency change, and amplitude systematically without presenting the more complex contour deformations that accompany actual contours.

Generally, the amplitude of oscillation decreases with duration due to friction, and the degree of the decrease depends on the degree of increased viscosity of the friction medium. In addition, the frequency of the oscillation depends on the *elastic* properties of the object. The frequency of oscillation of a high-elasticity object is higher than that of a low-elasticity object.

If material perception based on motion is related to such aspects of physical motion, the changes in amplitude and those in frequency might systematically shift visual material impressions such as elasticity and viscosity. In addition, manipulation of these two factors might reveal their correlation with the impression of hardness of an object because hardness, as a physical characteristic, is also dependent on elasticity, viscosity, and viscoelasticity.

Hence, if amplitude and frequency changes as aspects of motion are varied with the type of material, it might influence the visual impressions of hardness, viscosity, and elasticity.

Our purpose was to confirm whether amplitude and frequency changes in inducers' oscillation influence the visual impressions of an object's material properties such as hardness, elasticity, and viscosity.

2. Method

It should be noted that some details of the methods are reproduced here from Masuda et al. (2013).

2.1. Participants

Nine healthy adults (two female, seven male) aged 21–44 years participated in the experiment. They all had normal color vision and normal or corrected-to-normal visual acuity. This research followed the tenets of the Declaration of Helsinki. Written informed consent was obtained after a complete explanation of the study. The study was approved by the institutional ethics committee of the National Food Research Institute.

2.2. Stimuli and apparatus

Visual stimuli were controlled using a personal computer (Dell, Precision 390) and displayed at the center (600×600 pixels; 9.26×9.26 deg. in visual angle) of a 22-in. CRT monitor (resolution: 1024×768 pixels; diagonal visual angle: 19.72 deg.; Iiyama, HM204DA; 120 Hz refresh rate).

The stimuli consisted of four sets of three concentric circles (diameter: outer circle 1.98 deg., middle circle 1.23 deg., and inner circle 0.49 deg. of visual angle) presented on a white background. The line width of each circle was 0.12 deg. Each set of circles was placed in one corner of a square (distance between centers: 4.94 deg. of visual angle). The constructional lines of a quarter seg-

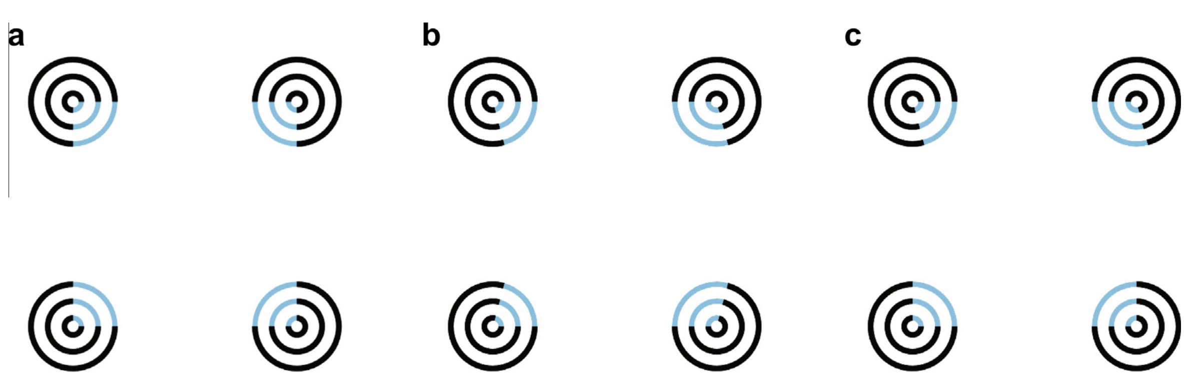

Fig. 1. Example of neon color spreading. (a) The typical figure in a static display, (b) an example figure for a kinetic display in the 0-deg. phase difference condition, and (c) an example figure for a kinetic display in the 90-deg. phase difference condition.