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Novel method of extracting motion from natural movies

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HIGHLIGHTS

- We propose a new method to extract object motion information from any natural movies.
- The extracted motion information can be visualized as random dot movies.
- Cells in area MT of common marmosets elicited comparable responses to the movies.
- This method innovates studies of integration of the shape and motion information.

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ABSTRACT

Background: The visual system in primates can be segregated into motion and shape pathways. Interaction occurs at multiple stages along these pathways. Processing of shape-from-motion and biological motion is considered to be a higher-order integration process involving motion and shape information. However, relatively limited types of stimuli have been used in previous studies on these integration processes.
New method: We propose a new algorithm to extract object motion information from natural movies and to move random dots in accordance with the information. The object motion information is extracted by estimating the dynamics of local normal vectors of the image intensity projected onto the *x*-*y* plane of the movie.
Results: An electrophysiological experiment on two adult common marmoset monkeys (*Callithrix jacchus*) showed that the natural and random dot movies generated with this new algorithm yielded comparable neural responses in the middle temporal visual area.
Comparison with existing methods: In principle, this algorithm provided random dot motion stimuli containing shape information for arbitrary natural movies. This new method is expected to expand the neurophysiological and psychophysical experimental protocols to elucidate the integration processing of motion and shape information in biological systems.
Conclusions: The novel algorithm proposed here was effective in extracting object motion information from natural movies and provided new motion stimuli to investigate higher-order motion information processing.

1. Introduction

1.1. Shape-from-motion as an interaction between pathways

In primates, the motion and shape pathways have been attributed to anatomically and functionally separable cortical streams, which are the dorsal and ventral visual pathways emerging from the striate cortex (Ungerleider and Mishkin, 1982). The dorsal visual pathway projects to the inferior parietal lobule and computes visuospatial information (Kravitz et al., 2011). The ventral visual pathway terminates at the anterior inferotemporal cortex and plays a role in enabling object identification (Kravitz et al., 2013). Many anatomical connections between the two neuronal pathways have been demonstrated at multiple stages (Baizer et al., 1991; Ungerleider et al., 2008; Webster et al., 1994), indicating functional interactions between motion and shape information processing (Perry and Fallah, 2014). Indeed, recent psychophysical studies have reported an influence of shape information on motion information by demonstrating that cues having a simple form (e.g., oriented lines or glass patterns) modulate motion detec-

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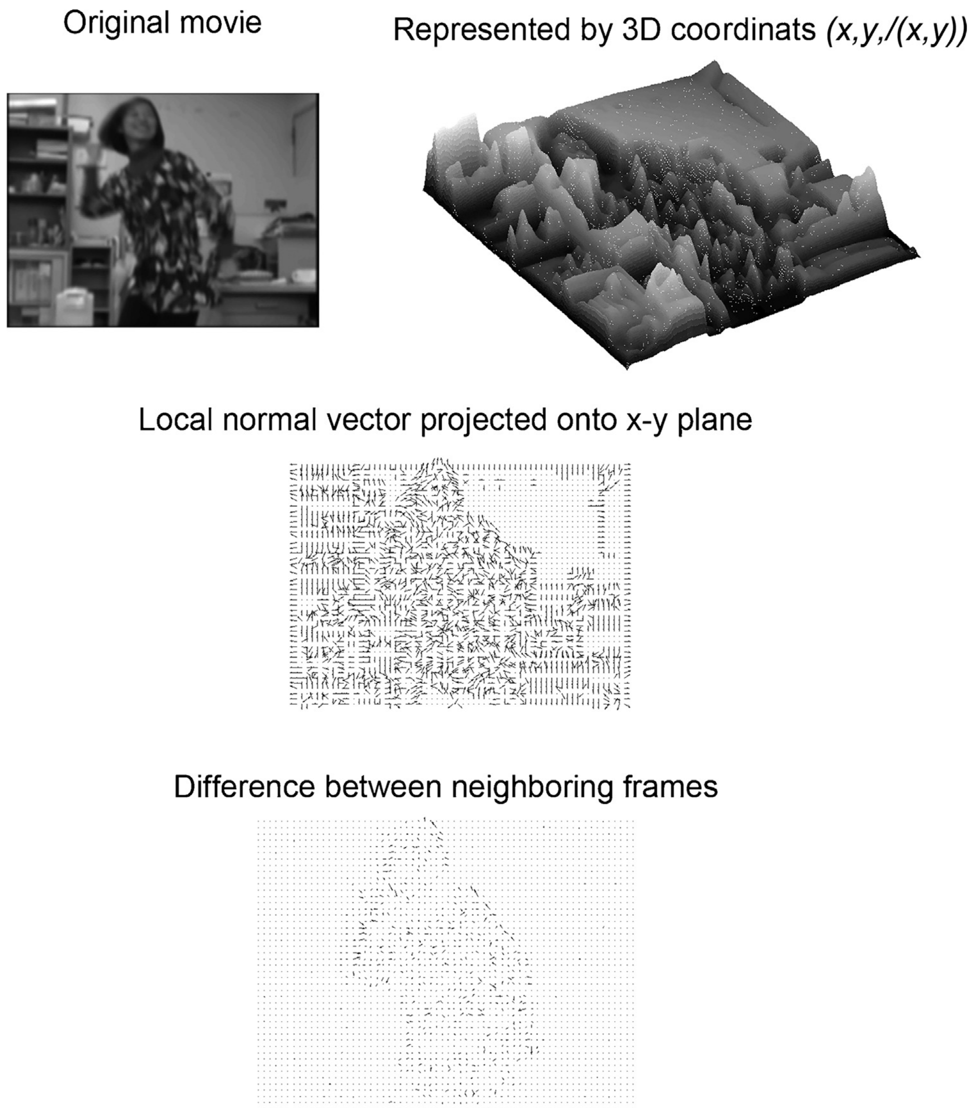

Fig. 1. Schematic of the algorithm to extract motion information from an original natural movie. The basic idea for extracting motion information from a natural movie is to estimate the dynamics of local normal vectors by calculating local normal vectors for each pixel in each frame of the movie and their time derivatives. A frame of an original natural movie (top left) is considered to be a curved surface ($x,y,/(x,y)$) in the three-dimensional space, which consists of the two-dimensional pixel position (x,y) of the frame and the luminance value $/(x,y)$ (top right). The normalized local normal vectors of the curved surface are calculated and projected onto the x-y plane (middle). The time derivatives of the projected local normal vectors are calculated as the difference between neighboring frames (bottom). Motion information is visualized on the basis of random dots that move in accordance with the dynamic vector field.

tion (Burr and Ross, 2002; Geisler, 1999; Krekelberg et al., 2003). Therefore, "shape-from-motion," which is the extraction of shape information from motion information, is one form of interaction. In this context, biological motion (Cutting, 1978; Johansson, 1973) seems to be processed differently from other stimuli of shape-from-motion in several aspects. When a few light markers are attached to a human body and the marked person moves in total darkness, the time series of the images of the light markers provides vast information about the age, gender, and even the emotions of the marked person to human observers. This type of stimulus shows asymmetry with respect to gravity (Pavlova and Sokolov, 2000; Sumi, 1984). These properties cannot be explained in terms of the general shape-from-motion algorithms.

1.2. Introducing a novel stimulus to study the pathway interaction

Higher-order processing of shape-from-motion has been explored using random dot motion illustrating geometrical figures, which are not sufficiently complex to cover the variety of motion embedded in natural vision. Although the light markers used in biological motion experiments enabled the extraction of rich information from their complex motion, the motion covered by the stimuli were generally limited to humans, a few other species such as pigeons, or a part of an animal's body such as the arm of a monkey (Hatsopoulos et al., 2007; Putrino et al., 2015), because of the difficulty in attaching the light markers. Visual stimuli that provide greater varieties of complex motion have been explored in the investigation of higher-order motion processing and the integration processing of shape and motion in neurophysiological and psychophysical experiments. In this study, we proposed a new algorithm to extract and separate the motion information from natural movies of humans, other animals, or artificial objects, and to move random dots in accordance with the information without any physical constraints. Although the computation in this algorithm was based only on local normal curvature vectors defined in the three-dimensional space ($x,y,/(x,y)$), where $/(x,y)$ is the luminance value at