

## Understanding the cognitive process of the human visual system by analysing illusions generated using a visual characteristics tester

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**Date:** 2025-11-23T00:00:00+00:00

### Abstract

Despite advances in vision research, how people see objects remains unclear. In this study, a WT5518 Visual Characteristics Tester imitating an electric fan was developed and used to investigate visual cognition. The tester could induce various visual illusions. Analysis of these visual illusions revealed that the human visual system consists of high- and low-speed visual subsystems, in which the visual brain processes visual information from the high- and low-speed visual pathways, and consciousness recognizes visual information from the visual brain. The two subsystems are independent of each other and do not interfere with each other, however, at some speeds, there is an intersection between the two subsystems. Furthermore, human vision comprises two states, i.e. the visual “filming state,” and “staring state.” During the “filming state,” consciousness captures and recognizes images from the high- and low-speed visual brain simultaneously, so, at this moment the individual can see the surrounding scenes. During the “staring state,” consciousness does not capture any images, thus, at this moment the individual cannot see the surrounding scenes. Ultimately, visual information is discrete and intermittent. In the “staring state,” vision stares at the images taken previously, therefore, the intermittence of visual information can hardly be perceived. Alternation of the two visual states endows human vision with frequency characteristics. The frequency at which consciousness samples visual information is 100 Hz. The cognitive behavior of people’s vision is synchronous. Both high- and low-speed vision subsystems can create illusions but only high-speed vision can create afterimages. This study provides a foundation for cognitive research.

## Full Text

### Preamble

Understanding the Cognitive Process of the Human Visual System Through Analysis of Illusions Generated by a Visual Characteristics Tester

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### Abstract

Despite significant advances in vision research, the fundamental mechanisms underlying human object perception remain incompletely understood. This study developed a WT5518 Visual Characteristics Tester, modeled after an electric fan, to investigate visual cognition. The apparatus successfully induced various visual illusions, whose analysis revealed that the human visual system comprises distinct high-speed and low-speed visual subsystems. In this framework, the visual brain processes information from both pathways, while consciousness is responsible for recognizing visual information from the visual brain. These two subsystems operate independently without mutual interference, though they intersect at certain speeds. Furthermore, human vision exhibits two distinct states: a visual “filming state” and a “staring state.” During the filming state, consciousness simultaneously captures and recognizes images from both high- and low-speed visual brain regions, enabling perception of the surrounding environment. During the staring state, consciousness captures no images, resulting in a temporary inability to perceive the surroundings.

Critically, visual information is discrete and intermittent. Because vision during the staring state continues to process previously captured images, the intermittent nature of visual information is rarely perceived. The alternation between these two visual states endows human vision with characteristic frequency properties. The frequency at which consciousness samples visual information is 100 Hz. The cognitive behavior of human vision is synchronous across individuals. While both high- and low-speed visual subsystems can generate illusions, only high-speed vision produces afterimages. These findings provide a novel foundation for cognitive research.

**Keywords:** Psychology, Neuroscience, Vision, Consciousness, Cognition

### Introduction

Human vision involves a complex system comprising the eyes, visual pathways, and the visual brain. The visual pathway system contains three separate and independent channels that process and transmit different aspects of the same retinal image to corresponding brain regions [?, ?]. The magnocellular pathway originates from rod photoreceptors and projects to M-cell layers in the lateral geniculate nucleus via large axons. The parvocellular pathway originates from

cone photoreceptors and projects to P-cell layers in the lateral geniculate nucleus via medium-sized axons [?]. The koniocellular pathway originates from bistratified retinal ganglion cells and projects to K-cell layers in the lateral geniculate nucleus via small axons [?, ?]. The parvocellular and magnocellular pathways demonstrate selectivity for object form/color and depth/movement, respectively. Notably, color, form, and motion are perceived at different times, with color perceived first [?]. Human vision is thus associated with a perceptual temporal hierarchy [?]. The visual brain subsequently combines these asynchronously perceived visual attributes to generate a unified experience of the visual world [?, ?, ?].

Partial damage to the visual system may result in partial loss of visual function, suggesting that the brain plays a crucial role in visual information recognition [?]. Many scientists believe consciousness is important for visual cognition [?, ?], yet the mechanisms by which consciousness recognizes visual information remain poorly explained. Through analysis of visual illusions, this study identifies general principles governing conscious recognition of visual information.

## Materials and Methods

### Ethics Statement

The study protocol was approved by the Medical Ethics Sub-Committee of the Science and Technology Ethics Committee of Nanjing University (OAP20230829001). Written informed consent was obtained from all participants. All experiments were performed in accordance with relevant guidelines and regulations.

### Participants and Experimental Equipment

A total of 72 volunteers (aged 20–70 years; 36 men and 36 women, excluding pregnant women) participated in the study and were randomly selected. Participants were divided into eight groups of nine individuals each. At the conclusion of each test, at least one participant from each group participated in subsequent tests. Participants stood or sat at distances ranging from 1 to 6 meters in front of the tester.

To investigate visual cognition, we developed the WT5518 Visual Characteristics Tester. The apparatus consisted of a motor with a flange mounted on its axis, to which several blades of different shapes were attached. Rotational speed was controlled via remote control, with clockwise rotation as the default direction. By varying the number and shape of blades on the flange and adjusting motor speed, the tester induced various visual illusions during experiments.

### Experiments

#### Experiment 1: Visual Phenomena Induced by Rotating Blades

Twelve identical white rectangular blades were installed on the WT5518 Visual Characteristics Tester at  $30^\circ$  intervals. The flange diameter (D) was 8 cm, blade length (L) was 11.3 cm, and width (W) was 1.3 cm, as shown in [Figure 1: see original paper].

[Figure 1: see original paper] Diagram of the experimental blade configuration. The flange diameter (D), blade length (L), and width (W) were adjustable parameters, and the number of blades could be varied.

As motor rotational speed increased, a series of remarkable visual phenomena emerged: (1) Between 0 and 62.5 rpm, all participants observed 12 white rectangular blades spaced at  $30^\circ$  intervals rotating clockwise. Blade clarity decreased with increasing speed, with outer blade portions appearing more blurred than inner portions at 62.5 rpm. (2) At 125 rpm, participants could still perceive the inner portions of the 12 white rectangular blades rotating clockwise. Simultaneously, all participants observed 48 identical fan-shaped blades spaced at  $7.5^\circ$  intervals appearing stationary, though the inner portions of these fan-shaped blades were invisible. The inner portions of the 12 white rectangular blades always overlapped with the outer portions of one group of 12 fan-shaped blades. (3) At a motor speed setting of 500 rpm (with possible minor deviation between actual and set speed), when actual speed equaled 500 rpm, all participants observed 12 fan-shaped blades fixed at 12 angles without rotation, as shown in Video 1. When actual speed slightly exceeded 500 rpm, all participants observed the 12 fan-shaped blades rotating slowly clockwise, as shown in Video 2. When actual speed was slightly below 500 rpm, all participants observed the 12 fan-shaped blades rotating slowly anticlockwise, as shown in Video 3. Due to inevitable speed fluctuations, participants perceived blades as sometimes stationary, sometimes rotating slowly clockwise, and sometimes rotating slowly anticlockwise. In all three cases, the 12 rectangular white blades disappeared completely from view. (4) At 501 rpm, all participants observed 12 fan-shaped blades rotating slowly clockwise, as shown in Video 2. (5) At 499 rpm, all participants observed 12 fan-shaped blades rotating slowly anticlockwise, as shown in Video 3.

### **Experiment 2: Visual Afterimages Induced by High-Speed Rotating Blades**

A white rectangular blade was installed on the flange, with a black rectangular blade of identical shape and mass mounted at  $180^\circ$  as a counterweight. Flange diameter (D) was 8 cm, blade length (L) was 11.3 cm, and width (W) was 3.0 cm ([Figure 1: see original paper]). At high rotational speeds, only the white blade was visible against the black background. At 750 rpm, all participants observed eight fan-shaped blades at  $45^\circ$  intervals without rotation. All participants experienced visual afterimages.

### **Experiment 3: Visual Illusions Induced by High-Speed Rotating Blades**

Six white rectangular blades were installed at  $60^\circ$  intervals. Flange diameter

(D) was 8 cm, blade length (L) was 11.3 cm, and width (W) was 2.0 cm ([Figure 1: see original paper]). When the motor rotated clockwise at 1,000, 500, 333.3, 250, 200, 166.7, 142.9, and 125 rpm, all participants observed 6, 12, 18, 24, 30, 36, 42, and 48 fan-shaped blades at  $60^\circ$ ,  $30^\circ$ ,  $20^\circ$ ,  $15^\circ$ ,  $12^\circ$ ,  $10^\circ$ ,  $8.6^\circ$ , and  $7.5^\circ$  intervals, respectively, all appearing stationary.

#### **Experiment 4: Investigation of Synchronized Cognitive Behavior in Low- and High-Speed Vision**

Forty-eight white rectangular blades were installed at  $7.5^\circ$  intervals. Flange diameter (D) was 8 cm, blade length (L) was 11.3 cm, and width (W) was 0.4 cm ([Figure 1: see original paper]). When the motor rotated clockwise at 125 rpm, all participants simultaneously observed 48 white rectangular blades and 48 fan-shaped blades that completely overlapped and remained fixed at 48 different angles without rotation, as shown in Video 4.

#### **Experiment 5: Visual Illusions Produced by Low-Speed Rotating Blades**

One hundred white rectangular blades were installed at  $3.6^\circ$  intervals. Flange diameter (D) was 13 cm, blade length (L) was 8.8 cm, and width (W) was 0.4 cm ([Figure 1: see original paper]). (1) At 60 rpm, all participants observed 100 white rectangular blades fixed at 100 different angles without rotation, as shown in Video 5. (2) At 62 rpm, all participants observed 100 white rectangular blades rotating slowly clockwise. (3) At 58 rpm, all participants observed 100 white rectangular blades rotating slowly anticlockwise.

All videos in this study were recorded at 30 fps from 60 cm in front of the tester. Some video-induced images matched those induced by the tester and served as demonstrations, while others differed and could not be used as demonstrations.

## **Results and Discussion**

### **Visual System Architecture: Dual Visual Subsystems and Conscious Recognition**

In Experiment 1(1), when 12 white rectangular blades rotated between 0 and 62.5 rpm, all participants perceived the blades spaced at  $30^\circ$  intervals rotating clockwise. This perception involved the low-speed visual subsystem. In Experiment 1(3), when the same blades rotated at 500 rpm, all participants perceived 12 fan-shaped blades fixed at 12 angles without rotation (Video 1), involving the high-speed visual subsystem. In Experiment 1(2), at intermediate speeds, participants could still perceive the 12 white rectangular blades rotating clockwise while simultaneously observing 48 fan-shaped blades spaced at  $7.5^\circ$  without rotation. The 12 white rectangular blades were identical to those in Experiment 1(1), thus engaging low-speed vision. The 48 fan-shaped blades resembled those in Experiment 1(3) but with one-quarter the area and four times the number, thus engaging high-speed vision. Since participants perceived both low- and high-speed visual information simultaneously, we infer that human vision

comprises distinct low-speed (perception of stationary or slowly rotating white rectangular blades) and high-speed (perception of rapidly rotating fan-shaped blades) visual subsystems.

Based on this analysis and established vision research, we propose the following architecture: The eyes, parvocellular system [?, ?], and one brain region constitute a high-speed visual sensor. The parvocellular system, composed of medium-sized cells, is sensitive only to high-speed motion information. This high-speed visual sensor, together with consciousness, forms high-speed vision ([Figure 2: see original paper]). The eyes, magnocellular system [?, ?], and another brain region constitute a low-speed visual sensor. The magnocellular system, composed of large cells, is sensitive only to stationary or low-speed motion information. This low-speed visual sensor, together with consciousness, forms low-speed vision ([Figure 2: see original paper]).

[Figure 2: see original paper] Schematic diagram of consciousness function. Consciousness continuously searches brain regions associated with the eyes, ears, nose, tongue, and body, identifying information from each modality.

Experiment 1(2) further demonstrated that high- and low-speed vision operate independently without interference, though they intersect at certain speeds. The eyes convert light information into bioelectrical signals, with high- and low-speed components transmitted to the visual brain via separate pathways. The visual brain processes these two information streams, but the information remains unrecognizable without consciousness. Consciousness must sample high- and low-speed visual information separately, comparing incoming data with stored knowledge to enable perception [?, ?]. Thus, visual cognition is impossible without consciousness [?, ?].

Clinical evidence supports this dual-subsystem architecture. Some patients with movement blindness (due to V5 cortical area damage) can see stationary objects but not moving ones. Others with form perception deficits (often accompanied by color blindness, seeing only gray shadows) have difficulty recognizing stationary objects but can perceive them when moving. Several observations support consciousness's essential role in visual recognition. First, visual information continuously transmits from eyes to visual brain, yet perception is discontinuous, suggesting consciousness—not the visual brain—is the ultimate destination. Second, different object attributes (color, shape, motion) arrive at the visual brain at different times, which cannot assimilate these asynchronous features. Instead, consciousness samples visual information from the visual brain, combines relevant attributes by comparing them with prior knowledge, and provides a unified visual world [?, ?]. Third, partial visual brain damage causing partial function loss does not necessarily reflect lost cognitive function; rather, damaged brain tissue loses information-processing capacity, preventing consciousness from accessing relevant visual information and resulting in functional loss.

Deep sleep illustrates how only consciousness, not the brain, recognizes information. When awake, consciousness continuously searches the auditory brain,

recognizing sound information enabling hearing. During deep sleep, consciousness does not search the auditory brain, rendering sounds inaudible.

### **High-Speed Vision: Discrete and Intermittent Information Processing**

In Experiment 1(3), despite continuous blade rotation, participants observed no rotation, suggesting high-speed vision operates like a movie camera, alternating between capturing visual information and pausing. When the capture frequency synchronizes with the motor's rotational frequency, blades appear fixed at specific angles without rotation (Video 1).

The working mechanism of high-speed vision is as follows: When consciousness examines the high-speed visual brain, vision enters the "filming state," during which consciousness captures one image from the high-speed visual brain. Consciousness then recognizes this image by comparing it with previous knowledge, enabling perception. When consciousness leaves the high-speed visual brain, vision enters the "staring state," during which consciousness captures no images and the external scene becomes invisible. Consciousness continuously alternates between filming and staring states, making high-speed visual information discrete and intermittent. During the staring state, high-speed vision continues to process previously captured information, making the intermittency difficult to perceive.

### **High-Speed Visual Frequency**

The alternation between visual states endows high-speed vision with frequency characteristics. In Experiment 1(3), at 500 rpm actual motor speed, all participants observed 12 fan-shaped blades fixed at 12 angles without rotation. High-speed vision captured one image per 30° of motor rotation, yielding 12 images per rotational cycle and 12 frequency synchronizations between visual capture and motor rotation (Video 1).

High-speed visual frequency can be calculated using equations (1) and (2), where  $n$  represents motor speed in rpm,  $f$  represents rotational frequency,  $f$  represents high-speed vision capture frequency, and  $T$  represents the filming period.

In Experiment 1(3):

$$f = f \times 12 = 8.33 \text{ Hz} \times 12 = 100.0 \text{ Hz}$$

$$T = 10 \text{ ms}$$

Numerous studies confirm that  $f = 100 \text{ Hz}$  is the sole operating frequency for high-speed vision. To verify this, a photoelectric sensor composed of infrared transmitting and receiving tubes was mounted on the tester base. The sensor emitted a pulse each time a blade passed. During each motor rotation, 12 blades produced 12 pulses. The total pulses per second equaled the high-speed vision system's capture frequency.

An 18F45K80 microchip served as the main controller. The photoelectric sensor output connected to the T1CKI timer input, with timer1 configured as a counter and timer0 set to 10-second intervals. After each interrupt, the chip read timer1 data, divided by 10, and calculated the number of blades passing per second—yielding 99.8–100.2 Hz. Using a UNI-T Digital Storage Oscilloscope (UTD2102CEX), immediate frequency measurement showed 99.2–100.5 Hz. While the two methods differed in averaging (10-second vs. immediate), the calculated high-speed visual frequency  $f$  always fell within both measurement ranges, confirming that  $f$  can be calculated from motor speed.

### Synchronous Cognitive Behavior in High-Speed Vision

In Experiment 1(3), all participants perceived 12 fan-shaped blades fixed at identical angles, indicating that all participants' high-speed vision entered filming and staring states simultaneously. This demonstrates that high-speed visual cognitive behavior is synchronous across individuals (Video 1). Experiments 1(3), (4), and (5) showed that if an individual's visual frequency differed by  $1/600$ , they would perceive slow clockwise rotation (Experiment 1(4)) or anti-clockwise rotation (Experiment 1(5)) while others saw stationary blades at 600 rpm.

Therefore, a “common visual clock” external to the human body must time consciousness. Based on human vision's frequency characteristics, we propose this common visual clock may be a pulsar with 50 Hz rotational frequency, emitting two pulses per rotation. Similar to quantum entanglement, an “entanglement effect” exists between vision and pulsar emissions, with pulses inducing simultaneous entry into the filming state and conscious image capture across all individuals.

### Temporary Storage Buffer for High-Speed Visual Information

Experiment 2 revealed the relationship between rotational speed  $n$ , number of perceived fan-shaped blades  $k$ , and rotational frequency  $f$ :

$$n = 6000/k \text{ (rpm)} \quad (k = 1, 2, 3, \dots)$$

For example, when  $k = 8$ , motor speed  $n_8 = 6000/8 = 750$  rpm. At this speed, all participants observed eight fan-shaped blades at  $45^\circ$  intervals without rotation. This demonstrates a “first-in, first-out” temporary storage buffer in high-speed vision. High-speed vision continuously extracts information from the high-speed visual brain, storing discrete image streams in this buffer. With rotational frequency  $f_8 = n_8/60 = 12.5$  Hz, high-speed vision obtained eight images per cycle because its capture frequency  $f = 100$  Hz was eight times  $f_8$ . Due to different capture times, adjacent images showed blades positioned  $45^\circ$  apart. Superposition of these eight discrete images in the buffer produced perception of eight stationary fan-shaped blades at  $45^\circ$  intervals, creating visual afterimages. The WT5518 Visual Characteristics Tester demonstrated that this

buffer can store at least eight images simultaneously; further research is needed to determine its maximum capacity.

Experiment 3 showed that high-speed visual illusions follow this general principle:

$$n \times k = 6000 / (i \times k) \text{ (rpm)} \quad (i \times k \leq 120)$$

where  $i$  represents installed blade count,  $k$  is a natural number, and  $n \times$  is motor speed. At speed  $n \times$ , all participants perceived  $i \times k$  stationary fan-shaped blades. This illusion arises from the same buffering mechanism. When  $i = 1$ , this reduces to the previous equation. If  $i = 12$  and  $k = 1$ , then  $n_{12} = 6000/12 = 500$  rpm. At this speed, participants perceived 12 fan-shaped blades at  $30^\circ$  intervals without rotation, equivalent to Experiment 1(3). Since the 12 blades were identical, the image after  $30^\circ$  rotation was identical to the original. With capture frequency 12 times the rotational frequency, high-speed vision captured 12 images per cycle (one every  $30^\circ$ ), storing them sequentially in the buffer. If buffer capacity is 8, all eight stored images are identical, and their superposition yields perception of 12 stationary fan-shaped blades.

If  $i = 12$  and  $k = 4$ , then  $n_{48} = 6000/48 = 125$  rpm. At this speed, participants perceived 48 fan-shaped blades at  $7.5^\circ$  intervals without rotation, equivalent to Experiment 1(2). With capture frequency 48 times the rotational frequency, 48 images were captured per cycle (one every  $7.5^\circ$ ). Images 1 and 5, 2 and 6, 3 and 7, and 4 and 8 were identical. Superposition of these eight images in the buffer produced perception of 48 stationary fan-shaped blades.

### Visual Illusions of Clockwise and Anticlockwise Rotation

When motor speed equals  $n \times + n \times$  rpm, observers perceive slow clockwise rotation. For example, with  $i = 12$  and  $k = 1$ ,  $n_{12} \times 1 + 1 = 501$  rpm. At this speed, all observers perceived slow clockwise rotation (Experiment 1(4), Video 2). This illusion can be explained using a single-blade system ([Figure 3: see original paper]).

[Figure 3: see original paper] Diagram of clockwise rotation illusion. The blade rotates rapidly clockwise, while observers perceive slow clockwise rotation.

When high-speed vision enters the filming state, all observers see the blade at position A. During the subsequent staring state, observers continue processing the captured information without seeing the actual rotating blade. When the filming state recurs, increased rotational speed has moved the blade to position B. Because angle  $\alpha >$  angle  $\beta$  (following Gestalt principles of perceptual organization), observers perceive the two blades with included angle  $\beta$  as a unified whole, resulting in perception of slow clockwise rotation from A to B.

Conversely, when motor speed equals  $n \times - n \times$  rpm, observers perceive slow anticlockwise rotation. With  $i = 12$  and  $k = 1$ ,  $n_{12} \times 1 - 1 = 499$  rpm produces

this effect (Experiment 1(5), Video 3), explained by a similar single-blade system ([Figure 4: see original paper]).

[Figure 4: see original paper] Diagram of anticlockwise rotation illusion. The blade rotates rapidly clockwise, while observers perceive slow anticlockwise rotation.

During the filming state, observers see the blade at position A. In the subsequent staring state, they process captured information without seeing the actual blade. When filming state recurs, decreased rotational speed has moved the blade only to position B (short of position A). Because angle  $\alpha >$  angle  $\beta$ , observers perceive the blades with included angle  $\beta$  as a unified whole, resulting in perception of slow anticlockwise rotation from A to B.

### **Characteristics of High-Speed Vision**

When capturing images from the high-speed visual brain, blades rotate at high speed. During the filming state duration, the perceived image is a fan-shaped area formed by blade rotation. The parvocellular system in high-speed vision functions like a high-pass filter, transmitting only high-speed motion information within a specific range to the high-speed visual brain while blocking low-speed rotation information. At 125 rpm, inner blade portions disappeared first from high-speed vision because their linear speed was slower than outer portions. At 62.5 rpm, fan-shaped blades completely disappeared from high-speed vision.

### **Low-Speed Vision**

#### **Synchronized Cognitive Behavior with High-Speed Vision**

Experiment 4 demonstrated synchronized cognitive behavior between low- and high-speed vision, implying that low-speed visual information is also discrete and intermittent (Video 4). Since low-speed vision also operates at 100 Hz, this can be termed human visual frequency. Participants' low-speed visual cognitive behavior is synchronous across individuals.

#### **Temporary Storage Buffer for Low-Speed Visual Information**

Low-speed visual information is discrete and intermittent, though the intermittency is difficult to perceive, indicating a temporary storage buffer for low-speed visual information. Experiments 4 and 1(2) both used 125 rpm. In Experiment 4 with 48 white rectangular blades, participants perceived 48 white rectangular blades. In Experiment 1(2) with 12 white rectangular blades, participants perceived 12 white rectangular blades without afterimages. This indicates that the low-speed visual information buffer can store only one piece of visual information.

#### **Illusions Induced by Low-Speed Rotating Blades**

Experiments 4 and 5(1) showed that when motor speed and blade count satisfy equation (6), all participants perceived  $m$  stationary white rectangular blades

(Video 5):

$$n = 6000/m \text{ (rpm)} \quad (m \geq 48)$$

Equation (6) resembles equations (4) and (5), but while  $k$  and  $i \times k$  in those equations include afterimages,  $m$  in equation (6) represents only actual blade count, with  $m \geq 48$ . Experiments 5(1), (2), and (3) demonstrated that low-speed vision can produce illusions similar to high-speed vision.

### Characteristics of Low-Speed Vision

Low-speed vision enables perception of object color, form, position, and depth at rest or during low-speed motion. The magnocellular system in low-speed vision functions like a low-pass filter, transmitting stationary or slow-motion information to the low-speed visual brain while blocking fast-motion information. Between 0 and 62.5 rpm, 12 white rectangular blades were visible. At 62.5 rpm, outer blade portions blurred more than inner portions because outer linear speed exceeded inner speed. At 500 rpm, the 12 white rectangular blades disappeared completely.

## Supplemental Information

### Video 1. Illusion of Stationary High-Speed Rotating Blades (MP4)

Twelve identical white rectangular blades were installed at  $30^\circ$  intervals. Flange diameter (D) was 8 cm, blade length (L) was 11.3 cm, width (W) was 1.3 cm. At 500 rpm set speed (with minor actual speed deviation), when actual speed equaled 500 rpm, all participants perceived 12 fan-shaped blades fixed without rotation at 12 angles.

<https://pan.baidu.com/disk/main?from=homeFlow#/index?category=1>

When actual speed slightly exceeded 500 rpm, all participants perceived slow clockwise rotation, as shown in Video 2.

<https://pan.baidu.com/disk/main?from=homeFlow#/index?category=1>

When actual speed was slightly below 500 rpm, all participants perceived slow anticlockwise rotation, as shown in Video 3.

<https://pan.baidu.com/disk/main?from=homeFlow#/index?category=1>

### Video 2. Illusion of Slow Clockwise Rotation (MP4)

Twelve identical white rectangular blades installed at  $30^\circ$  intervals (D = 8 cm, L = 11.3 cm, W = 1.3 cm). At 501 rpm clockwise rotation, all participants perceived 12 fan-shaped blades rotating slowly clockwise.

<https://pan.baidu.com/disk/main?from=homeFlow#/index?category=1>

### Video 3. Illusion of Slow Anticlockwise Rotation (MP4)

Twelve identical white rectangular blades installed at  $30^\circ$  intervals (D = 8 cm, L = 11.3 cm, W = 1.3 cm). At 499 rpm clockwise rotation, all participants

perceived 12 fan-shaped blades rotating slowly anticlockwise.

<https://pan.baidu.com/disk/main?from=homeFlow#/index?category=1>

#### **Video 4. Synchronous Low- and High-Speed Vision (MP4)**

Forty-eight white rectangular blades installed at 7.5° intervals (D = 8 cm, L = 11.3 cm, W = 0.4 cm). At 125 rpm clockwise rotation, all participants simultaneously perceived 48 white rectangular blades and 48 fan-shaped blades completely overlapped and stationary at 48 angles.

<https://pan.baidu.com/disk/main?from=homeFlow#/index?category=1>

#### **Video 5. Illusion of Stationary Low-Speed Rotating Blades (MP4)**

One hundred white rectangular blades installed at 3.6° intervals (D = 13 cm, L = 8.8 cm, W = 0.4 cm). At 60 rpm clockwise rotation, all participants perceived 100 white rectangular blades fixed at 100 angles without rotation.

<https://pan.baidu.com/disk/main?from=homeFlow#/index?category=1>

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<https://doi.org/10.1007/s11427-021-1938-8>

## Acknowledgements

I thank Prof. Huan-Liu Hou for manuscript proofreading and Qian Huang for image preparation.

## Data Availability

All data supporting this study' s findings are contained within the manuscript.

## Author Information

Lai-You Huang designed the study, performed experiments, analyzed data, and wrote the manuscript.

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## Ethics Declarations

The study protocol was approved by the Medical Ethics Sub-Committee of the Science and Technology Ethics Committee of Nanjing University (OAP20230829001). Written informed consent was obtained from all participants. All experiments were performed in accordance with relevant guidelines and regulations.

## Declaration of Competing Interests

The author declares no competing interests.

*Note: Figure translations are in progress. See original paper for figures.*

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