Motion Transparency Perception at Different Speeds and Simulation Analysis of Bi-stimuli Integration

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This report mainly discuss my work in a one-month summer internship in Department of Neuroscience, University of Wisconsin - Madison. The main work can be divided into two aspects: conducting a psychophysical experiment and designing an interface for simulation. In natural scenes, multiple entities are often present simultaneously in the same spatial region, therefore, it is crucial to learn the mechanism behind the segmentation of the multiple motion vector by the visual system. In the psychophysical experiment, we focus on the human perception of bi-speed stimuli. The main finding is that there was no significant difference between human perceived speed evoked by bi-speed stimuli and their ideal velocity, except for several exceptions. It indicates that human may be able to extract two speed components in motion transparency. The graphical user interface functions well in providing simulation with users' setting, and can serve as a useful tool for researchers to fit the models with the real neuron data.

Keywords: visual perception, bi-speed, simulation, integration

Introduction

Motion transparency refers to the perception of overlapping motion vectors in the same spatial region. In most circumstances, spatial cues indicate the segmentation to help visual system extract multiple motion vector at the same time. But in the case of motion transparency, the cues are absent, making it a challenging problem for visual system to process the segmentation(Gaudio and Huang, 2012).

It has been well established that the perceived direction separation between two transparently moving random-dot stimuli is wider than the actual direction separation(Benton and Curran, 2003). However, it remains unclear that how perceived speed separation in. In order to address this problem, a series of psychophysical experiments were conducted to find out the influence of bi-speed stimuli. We hypothesize that the separation can be magnified in human perception.

In natural scenes, multiple entities are often present simultaneously in the same spatial region(Xiao and Huang, 2015). Therefore, it is crucial to understand the interaction between different segmentations of visual stimuli. Entities in natural sceces always have different surfaces and distances to the observer. However, it is still unclear how multiple stimuli within neurons' receptive fields (RFs) interact to influence neuronal responses. Various models such as the summation plus nonlinear interaction (SNL) model(Xiao et al., 2014) have been proposed to match the process. In order to help the researchers fit the models with the collected real neuron data, an application of model simulation with useful functions like changing the parameters, plotting the figure and saving the data has been written.

In this report, the following work has been done:

1. Collect and analyze data of human visual speed perception of bi-speed stimuli;
2. Create a graphical user interface for simulation of bi-stimuli integration.

Methods and Materials

Psychophysical Experiment

The experimental procedure was referred to the work conducted by Chuang et al(2016).

Apparatus. Visual stimuli were generated by a Linux workstation using an OpenGL application and displayed on a 19-in. CRT monitor. The monitor had a resolution of $1,024\times$ 768 pixels and a refresh rate of 100 Hz. The output of the video monitor was measured with a photometer (LS-110, Minolta) and was gamma corrected. Stimulus presentation was controlled by a data acquisition and stimulus control program called "Maestro" (https://sites.google.com/a/srscicomp.com/maestro). The experimental control computer communicated with the stimulus presentation computer via a dedicated Ethernet link. Subjects viewed the visual stimuli in a dark room with a dim background illumination. The viewing distance

We would like to acknowledge all of the many people who contributed to this work.

was 58 cm. A chin rest and a forehead support were used to restrict head movements of the observers.

Subjects. Two women adult subjects, with normal or corrected-to-normal visual acuity, participated in the experiment. Both of the subjects, FW and DW, were familiar with the purposes of the experiments.

Visual stimuli. There were two kinds of visual stimuli: test stimuli and comparison stimuli. Test stimuli were two spatially-overlapping random-dot patches presented within a circular aperture of 10° wide. The random dots were achromatic. Each random dot was 3 pixels and had a luminance of 15.0 cd/m2. The background luminance was 0.03 cd/m2. The dot density of each random dot patch was 2π dots/degree. The lifetime of each dot was as long as the presentation duration. The two random-dot patches translated horizontally in the same direction (rightward) at two different speeds. The ratio between the speeds of the two stimulus components was fixed in each block of trials. For comparison, the stimuli shared all the properties with test stimuli except that the stimulus speed of them were varied from trial to trial in a staircase procedure.

Therefore, a fixed ratio between the two speed components gave rise to a fixed speed difference in the logarithmic scale. One set of stimuli there was a "large speed difference" between the two stimulus components; the speed of the faster component was always four times the speed of the slower component. In three different stimulus conditions, the speeds of the slower and faster stimulus components were 2.5 and 10°/s; 5 and 20°/s; 10 and 40°/s, respectively. In a second set of stimuli there was a "small speed difference" between the two stimulus components; the speed of the faster component was always twice the speed of the slower component. The slower and faster speed components were 2.5 and 5°/s; 5 and 10°/s; 10° and 20°/s, respectively. In the future work, more pairs of speed will be added to enrich the experiment. The logarithmic mean was taken from each speed pairing to give single speed trials. The calculation of Mean Speed (MS) was given by below**1**:

$$MS = 10 \times \{[\log(\text{Spd1}) + \log(\text{Spd2})]/2\} \quad (1)$$

The random dots. The random dots moved at one of two set coherence values within a stationary aperture. The coherence was always set at 100%. At 100% coherence, all dots in the patch moved coherently in the rightward direction.

Procedure. All visual stimuli were presented in individual trials while subjects fixed on a spot on the video display center, whose color was initially set to achromatic. In the beginning of a trial, visual test stimulus was centered on the display and was first turned on moving for 500 ms. Then, the test stimulus turned off and the fixation spot turned red or green and kept its state for 750 ms. The red color indicated that the subject should compare the speed of the slower component in the test stimulus with the following comparison stimilus, while greed color implied that of the faster component. After the cue section, the comparison stimulus lasted for another 500 ms. In this period, the focal spot kept white. Following the offset of the comparison stimulus, each subject had 1500 ms to report their perceptual judgment by pressing one of two buttons (2AFC). This response period was indicated to the subject by the focal point changing from a white spot to a yellow spot. The next experimental trial started immediately after the response period ended. The pipeline was shown as in Figure 1.

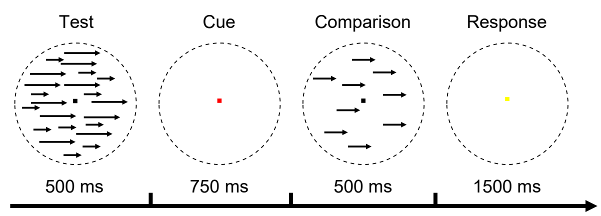

Figure 1. Visual stimuli and the experimental paradigm.

Visual stimuli were composed of achromatic random dots. The "test" stimulus was composed of a center patch, where random dots moved coherently at two different speeds to the right. Note that the number of dots moving at each speed was always the same. In the "cue" period, the color of the fixation spot served as clue for subjects to know which speed to concern. The figure shows the case that subjects should compare the slower component in "test" stimulus with "comparison" stimulus. If the color was green, subjects should compare the faster one. The "comparison" stimulus was the same as the center patch of the test stimulus, except that the speed of the comparison stimulus was varied from trial to trial, according to a staircase procedure. The test stimulus was presented first for 500 ms, followed by a 750-ms interstimulus interval (ISI) as the "cue" period, and the comparison stimulus was presented for 500 ms. Subjects were instructed to determine whether the motion speed of the center patch of the test stimulus was faster or slower than the speed of the comparison stimulus in the following period. The Response period lasted 1500 ms and the fixation spot was yellow during this period.

We used a staircase method to determine the perceived speed of the center patch of the test stimulus. Two staircases were applied simultaneously in a single block, aiming to measure the perception of the faster or slowly component in the test stimuli respectively. Once a subject had completed all trials to finish two staircases, this was considered a block. In each staircase, the speed of the signal dots in the test stimulus was fixed, and the speed of the comparison stimulus was varied adaptively at a step of 1°/s or 0.5 °/s only in the case including speed of 2.5°. The initial speed of the comparison stimulus was set randomly within the range from 1°/s to twice of the veridical speed of the signal dots in the test stimulus. When the subject reported that the comparison speed was faster (or slower) than the test speed in a given trial, the speed of the comparison stimulus was decreased (or increased) in the following trial. A "reversal" speed was reached when the subject switched from reporting the comparison stimulus as faster to slower, or vise versa. The staircase was stopped after ten reversals, and we determined the matching speed as the mean of the last four reversals. After a subject's performance was stabilized via practice, we conducted four or five staircases for each stimulus condition and calculated the mean matching speed. The two or four multiple blocks were given in random order.

Simulation Interface

The simulation was independent of the psychophysical experiment. It was used for other experiments conducted by some group members. The Simulation interface was generated on MATLAB 2018b, verified to support all the versions after MATLAB 2017. In the following analysis, the basic rules and functions are explained.

The responses of stimulation are fitted by von Mises function(Forbes et al., 2010), which is given by:

$$f(x|\mu,\kappa) = \frac{e^{\kappa\cos(x-\mu)}}{2\pi I_0(\kappa)} \quad (2)$$

where x is the motion direction of the unidirectional stimulus, μ is the direction where the tuning curve reaches its peak (the neuron's preferred direction), and $I_0(\kappa)$ is the modified Bessel function of order 0.

Suppose R_1, R_2 are the firing rates evoked by stimulation delivered by component 1 and component 2 of overall stimulation, respectively, the von Mises function can be simplified as:

$$R_1(\theta_1) = A_1 + B_1 e^{C_1[\cos(PD-\theta_1)-1]} \quad (3)$$

$$R_2(\theta_2) = A_2 + B_2 e^{C_2[\cos(PD-\theta_2)-1]} \quad (4)$$

where θ_1,$\theta_2$are the stimulation's direction of component 1 and 2, respectively, and PD is the preferred angle of the neuron. B and C determine the magnitude and bandwidth of the tuning curve, respectively, and A is a constant. The indexes of parameters A, B, C indicate different segmentations of stimulation.

The model constructed to fit the overall response of combined stimulation added a nonlinear interaction to the weighted linear sum model, which is referred to as the summation plus nonlinear interaction (SNL) model(Vokoun et al., 2014). Assume that R_{12} is the firing rate of the overall stimulation, then the model will be given by:

$$R_{12}(\theta_1,\theta_2) = \omega_1 R_1(\theta_1) + \omega_2 R_2(\theta_2) + bR_1(\theta_1)R_2(\theta_2) + c \quad (5)$$

where ω_1,ω_2 are response weights and b represents the weight for nonlinear interaction. The constant c is always set to zero in this simulation. In the simulation, R_1 and R_2 are generated by users' input parameters. Gaussian noise is applied to the firing rates, whose mean and standard deviation can also be determined by users.

Results

Human visual perception

To gain a better understanding of the interaction of each component in the bi-speed stimuli, we asked the question of how simultaneously presented and different motion velocities influence the human speed perception. We collected speed reports from two human subjects as they viewed the bi-speed stimuli used in our psychophysical experiments (). Note that one of the subjects, Di, only took part in limited experiments. There were six conditions of each kind of bi-speed stimuli: three pairs of points for fourfold difference and three for twice. The results of fourfold conditions can be organized as shows in Figure 2. The percieved speed seemed stable with its value approaching to the ideal. We noticed that all of the perceived speed have no statistical difference with ideal except the value of 20°/s, according to T test. The similar phenomenon happened in the case of twice difference, as Figure 3 shows.

There is one potential factor that can interfere the results. It may be harder for the subject to delect the lower edge of the transformation than the higher edge. In order to eliminate this possible effect, we set the initial strength of the staircase randomly, conforming to uniform distribution. According to our records, there is no obvious disturbance in results caused by the variation starting strength.

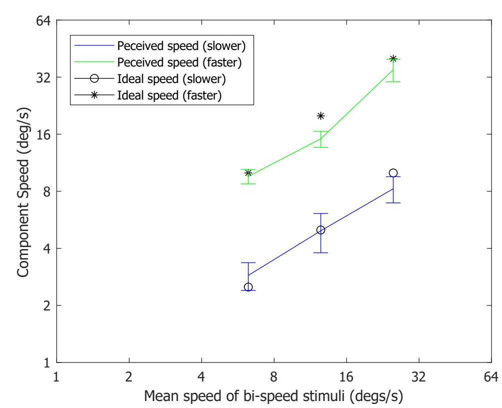

Figure 2. The perceived speed of the bi-speed stimuli when the faster component was four times faster than the slower.

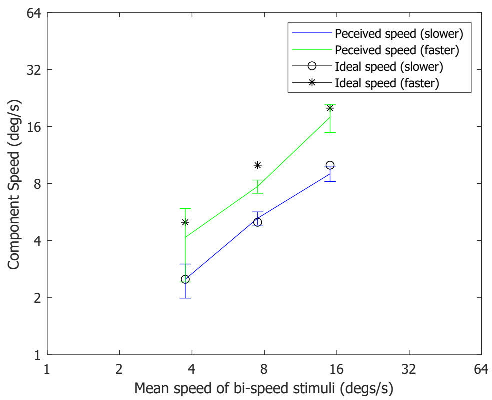

Figure 3. The perceived speed of the bi-speed stimuli when the faster component was two times faster than the slower.

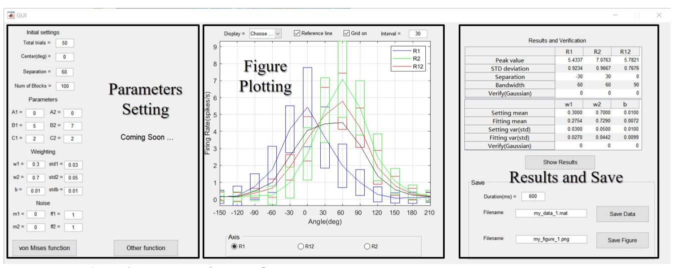

Figure 4. The user interface.

Simulation Interface

Simulation is a Graphical User Interface (GUI) within which simulation can be defined, executed, and monitored. The interface can be divided into three parts: Parameters Settings, Figure Plotting, Results and Save. Parameters Setting area is dedicated to editing a series of relevant parameters to determine the simulation. Figure Plotting area plots the tuning curves whose y-axis represents firing rate. In this area, users are also able to choose some display alternatives. Results and Save area display the values and verifications of the parameters and data. After "Save Data" button is pressed, results will be saved in MATLAB document, titled by the filename provided by users. "Save Figure" button save the axes in Portable Network Graphic (.PNG), which is the only format it supports for the time being. The uesr's interface is shown as Figure 4.

Discussion

In the psychophysical experiment, most of perceived speeds were not significantly different from the ideal velocity. This implies that human may be able to detect and separate the two components with different speed at the same direction. Interestingly, we notices that the velocity of 20°/s was always underestimated in perception. We speculates that this may because of confusion in the certain velocity. Subjects may use the slower component as clue and therefore regard the faster one slower. However, other participants may have a different perception with the subjects taking part in the experiment, so the reason remains unknown to us.

Regretfully, the samples may be not sufficient enough to support the conclusion, since the number of participants. In future study, if more pairs of speed can be added to the experiment, we will discover more thorough conclusion on the topic. Several questions are waiting for solution, for example, the relationship between the mean speed of bi-speed stimuli and their visual perception, or the influence of the difference between the two velocities applied to the stimuli. Besides, since the software Maestro only support limited paradigm, if we use the psychtoolbox provided by MATLAB, the design of experiment can be more flexible to study more

The simulation only support the von Mises distribution temporarily. With the same flow of poccess, researchers can easily edit the MATLAB functions and add more models to cater to their own hypothesis.

References

Benton, C. P. and Curran, W. (2003). Direction repulsion goes global. *Current Biology*, 13(9):767 – 771.

Chuang, J., Ausloos, E. C., Schwebach, C. A., and Huang, X. (2016). Integration of motion energy from overlapping random background noise increases perceived speed of coherently moving stimuli. *Journal of Neurophysiology*, 116(6):2765–2776. PMID: 27683893.

Forbes, C., Evans, M., Hastings, N., and Peacock, B. (2010). *von Mises Distribution*, chapter 45, pages 191–192.

Gaudio, J. L. and Huang, X. (2012). Motion noise changes directional interaction between transparently moving stimuli from repulsion to attraction. *PLOS ONE*, 7(11):1–6.

Vokoun, C. R., Huang, X., Jackson, M. B., and Basso, M. A. (2014). Response normalization in the superficial layers of the superior colliculus as a possible mechanism for saccadic averaging. *Journal of Neuroscience*, 34(23):7976–7987.

Xiao, J. and Huang, X. (2015). Distributed and dynamic neural encoding of multiple motion directions of transparently moving stimuli in cortical area mt. *Journal of Neuroscience*, 35(49):16180–16198.

Xiao, J., Niu, Y.-Q., Wiesner, S., and Huang, X. (2014). Normalization of neuronal responses in cortical area mt across signal strengths and motion directions. *Journal of Neurophysiology*, 112(6):1291–1306. PMID: 24899674.