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MODIFYING THE METHOD OF CONSTANT STIMULI TO ANALYZE THE PERCEPTION OF A COMPLEX STIMULUS

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Abstract. In this study, we modify the Method of Constant Stimuli (MCS) in order to test the human perception of a complex property of a stimulus that cannot be tested by using the traditional MCS. Note that the traditional MCS is often used to estimate the *differential threshold* of some simple image property, such as its orientation, depth-order, vernier-offset, or curvature. Our modified MCS reduces the complexity of the stimulus by assuming that the perception of a complex stimulus can be explained as the sum of the perception of the simple components it contains. This assumption allowed us to examine the Gestalt-like effect caused by complexity by comparing the results obtained with our modified MCS and the traditional MCS.

Keywords: Method of Constant Stimuli, psychophysics, Gestalt Psychology, maximum likelihood estimation

The traditional Method of Constant Stimuli (MCS; Gescheider, 1985) assumes that an independent variable *x* of a stimulus is a scalar variable that ranges from −∞ to +∞. A human participant judges whether *x* of a given stimulus is larger or smaller than a criterion c (the criterion c can be given as a comparison stimulus). The traditional MCS used with the Two-Alternative-Forced-Choice method allows us to estimate a differential threshold of *x* while eliminating any response-biases but it can only be used to study the perception of a *simple* property of a simple visual stimulus (e.g. one or two line-segments, one or two dots, or a grating, see Andrews et al., 1973; Watt, 1984; and Heeley, Buchanan-Smith, 1990 for examples). Note that the perception of a complex stimulus can be explained as the sum of the perception of simple image properties that make up a complex stimulus based on reductionism (i.e., by assuming there are no holistic or gestalt-like effects). In this study, we propose a new method for estimating the differential threshold of a complex property of a visual stimulus by modifying the traditional MCS.

The traditional MCS is based on the assumption that a likelihood distribution of the perception of *x* can be represented by a one-dimensional normal distribution whose center is at *x*. The standard deviation of the distribution is independent from *x*. In a psychophysical experiment using the traditional MCS, the independent variable *x* takes several different values and percent correct of a human participant is measured for each value of *x*. Then, the percent correct is plotted as a function of x and a cumulative normal distribution function is fitted to this plot. The standard deviation of the cumulative distribution function is equivalent to the standard deviation of the likelihood distribution. In other words, the MCS can be modified for some stimulus property that does not follow from the basic assumptions of the traditional MCS if a likelihood distribution of the perception of the property can be determined. If this is the case, a function for fitting the psychophysical result can be derived from the likelihood distribution.

Derivation

To simplify the derivation, we will consider a visual stimulus composed of N line-segments and the perception of their orientations. A differential threshold of an orientation of each line-segment can be estimated using the traditional MCS.[1] But, this traditional method cannot be applied to study perception of parallelism among a set of N line-segments. The line-segments can be represented by a point $X = [\theta_1, \theta_2, \cdots \theta_N]^t$ in an N-dimensional space and its N coordinates are corresponded with the orientations of the line-segments individually. Note that $\theta_1 = \theta_2 = \cdots = \theta_N$ if the line-segments are perfectly parallel to one another. If this is the case, the deviation of the line-segments from being parallel to one another can be characterized as

$$\|X\| = \sqrt{\frac{\sum_i^N (\theta_i - \bar{\theta})^2}{N}}$$

where $\bar{\theta}$ is an average of all the coordinates of X

$$\bar{\theta} = \frac{\sum_i^N \theta_i}{N}$$

The deviation $\|X\|$ is a scalar but $\|X\| \geq 0$. So, the traditional MCS cannot be used to estimate the differential threshold of $\|X\|$.

The likelihood distribution of an orientation θ_i of each line-segment is

$$L(\dot{\theta}_i | \theta_i, \sigma_i) = \frac{1}{\sqrt{2\pi{\sigma_i}^2}} e^{-\frac{\left(\dot{\theta}_i - \theta_i\right)^2}{2{\sigma_i}^2}}$$

where σ_i is an orientation differential threshold. Note that σ_i depends on different factors in the visual stimulus, for example the orientation of the segment (e. g. Westheimer, 2001), the position of the segment (e. g. Mäkelä et al., 1993), and the length of the segment (e.g. Andrews, 1967). The visual stimuli used in a psychophysical experiment should be controlled so that σ_i can be

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[1] Note that when the dimension of an orientation is circular, it violates the assumption that the dimension ranges from −∞ to +∞. This violation is not critical when using the MCS because the differential threshold for the orientation of a line-segment is substantially smaller than the cycle of the dimension (180°) (e.g. Westheimer, 2001; Mäkelä et al., 1993; Andrews, 1967).

approximated to be a constant σ. If this is not done, these factors should be represented as additional dimensions of the stimulus space. When it is done, the likelihood distribution of perception of X is

$$L(\dot{X}|X,\sigma) = \prod_{i}^{N} L(\dot{\theta}_i|\theta_i,\sigma)$$

where $\dot{X}$ is the perception of X from the visual stimulus. A likelihood distribution of the perception of $\|X\|$ is

$$L(\|\ddot{X}\||X,\sigma) = \int_{\|\dot{X}\|=\|\ddot{X}\|} L(\dot{X}|X,\sigma)d\dot{X}$$

where $\|\ddot{X}\|$ is perception of $\|X\|$ from the visual stimulus.

In a psychophysical experiment using the modified MCS proposed in this study, the responses of a human participant are collected by using the Two-Alternative-Forced-Choice method. Here, the participant is shown two visual stimuli with different values of X (X_A and X_B) sequentially in each trial and judges whether $\|X_A\| > \|X_B\|$ or $\|X_A\| < \|X_B\|$. The two-dimensional likelihood distributions of the perception of $\|X_A\|$ and $\|X_B\|$ is computed as

$$L(\|\ddot{X}_A\|,\|\ddot{X}_B\||X_A,X_B,\sigma) = L(\|\ddot{X}_A\||X_A,\sigma)L(\|\ddot{X}_B\||X_B,\sigma)$$

The probability that the participant perceives $\|X_A\| > \|X_B\|$ is calculated as the ratio between the two integrals of the 2D likelihood distribution:

$$\frac{\iint_{\|\ddot{X}_A\|>\|\ddot{X}_B\|} L(\|\ddot{X}_A\|,\|\ddot{X}_B\||X_A,X_B,\sigma)\mathrm{d}\|\ddot{X}_A\|\mathrm{d}\|\ddot{X}_B\|}{\iint L(\|\ddot{X}_A\|,\|\ddot{X}_B\||X_A,X_B,\sigma)\mathrm{d}\|\ddot{X}_A\|\mathrm{d}\|\ddot{X}_B\|}$$

In this psychophysical experiment, $\|X_A\|$ is constant and $\|X_B\|$ is an independent variable that takes several different values for simplicity (Gescheider, 1985). The participant's percent correct is measured for each value of $\|X_B\|$ and is plotted as a function of $\|X_B\|$. σ can be estimated by using the maximum-likelihood method.

The estimated σ using our modified MCS method is mathematically equivalent to the orientation threshold σ_i of the individual line-segment that can be estimated by using the traditional MCS to reduce its complexity. Simply put, *the whole “is” the sum of its parts*. When the traditional MCS method is used, if the estimated σ of our modified MCS method *is smaller* than the estimated σ_i of the individual line-segment, suggests that there *is* a Gestalt-like effect on a property of the image (see Koffka, 1935). Note that this observation implies that there might be a special mechanism in the human visual system to process this image properly.

Discussion

We have discussed only the orientations of line-segments in this study. In the future, we will consider applying our modified MCS to other properties of a stimulus. Note that the derivation we used only considered visual stimulus properties in a single domain (orientation in this study). If this condition is satisfied, our method can be applied without any modification. However, it should be noted that our method does not consider a combination of properties in different domains. For example, judging whether a quadrilateral is, or is not, a square, requires both the orientations and the lengths of four line-segments. Such combinations of the properties in the different domains should be addressed in future modifications of the MCS.

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Модификация метода постоянных раздражителей для анализа восприятия сложных стимулов

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Аннотация. В этом исследовании мы модифицируем метод постоянных раздражителей (МПР), чтобы измерить восприятие человеком свойств сложных стимулов, которые не могут быть измерены с помощью традиционного МПР. Традиционный МПР часто используется для оценки разностного порога простых свойств стимулов, таких как, например, ориентация, глубина, смещение верньера, кривизна. Наш модифицированный МПР уменьшает сложность стимула путем допущения, что восприятие сложного стимула может быть представлено как сумма восприятий его простых компонентов. Это допущение позволило нам исследовать гештальт-подобный эффект, обусловленный сложностью свойства, путем сравнения результатов, полученных с помощью нашего модифицированного МПР и традиционного МПР.

Ключевые слова: метод постоянных раздражителей, психофизика, гештальт-психология, метод максимального правдоподобия