viewed the same scenes again in the same order and duration as previously. Participants rated each picture on the same 5-point scale used in Experiment 2.

Results and Discussion

Recall. The area of the scenes in participants' drawings were compared to estimates of the area the scenes should have subsumed (relative to object size) if participants' drawings were veridical reproductions of the scenes. In general, remembered area was significantly larger than actual area, $t(33) = 6.71$, $p < .001$; remembered area was significantly larger than actual area for the pictures of the lamp, $t(33) = 5.27$, $p < .001$, basketball, $t(33) = 6.06$, $p < .001$, horse, $t(33) = 8.09$, $p < .001$, and cup, $t(33) = 5.63$, $p < .001$.

Recognition. The mean rating ($M = -.50$) across objects was significantly less than zero, $t(33) = -6.63$, $p < .001$. Each picture showed significant boundary extension: lamp, $t(33) = -5.27$, $p < .001$, basketball, $t(33) = -6.06$, $p < .001$, horse, $t(33) = -8.09$, $p < .001$, and cup, $t(33) = -5.63$, $p < .001$.

Negative ratings in the recognition task are consistent with previous reports of boundary extension. A possible reason for the smaller remembered size is that in the recognition task, as well as in previous studies of boundary extension, the perimeter length of the boundary was kept constant (and object size allowed to vary). The incorporation of additional likely information from beyond the boundaries of the original scene necessitated a decrease in subsumed size of the central object. However, when object size was kept constant (and boundary location allowed to vary) in the recall task, remembered area increased, and this is consistent with an extension of the boundaries outward.

General Discussion

The experiments described here examined whether results typical of experiments on boundary extension could result from changes in remembered distances of 3-D objects (Experiments 1-2) and remembered size (Experiment 3). The data suggest (a) boundary extension is not due to changes in remembered distance or size, (b) memory for distance and size might be task dependent, and (c) boundary extension occurs when object size is constant in 2-D scenes.

References

Algom, D. (1992). Memory psychophysics: an examination of its perceptual and cognitive prospects. In D. Algom (Ed.), *Psychophysical approaches to cognition* (pp. 441-513). New York: North-Holland.

Hubbard, T. L. (1994). Memory psychophysics. *Psychological Research/Psychologische Forschung, 56,* 237-250.

Hubbard, T. L. (1996). Displacement in depth: representational momentum and boundary extension. *Psychological Research, 59*, 33-47.

Intraub, H. (2004). Anticipatory spatial representation of 3D regions explored by sighted observers and a deaf-and-blind-observer. *Cognition*, *94*, 19-37.

Intraub, H. (2002). Anticipatory spatial representation of natural scenes: momentum without movement? *Visual Cognition*, *9*, 93-119.

Intraub, H. (2001). Internalized constraints in the representation of spatial layout. *Behavioral and Brain Sciences, 24*, 677-678.

Intraub, H. & Richardson, M. (1989). Wide-angle memories of close-up scenes. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 179-187.

PHOTOGRAPHS OF MOUNTAINS TAKEN FROM A HIGHER ALTITUDE APPEAR TO MAKE THEM LOOK TALLER THAN PHOTOGRAPHS OF MOUNTAINS TAKEN FROM A LOWER ALTITUDE

Satoru Kawamura, Shuya Hashimoto and Yusuke Miyamoto
School of Human Sciences, Osaka University, 1-2 Yamadaoka, Osaka 565-0871, Japan
<satoru@hus.osaka-u.ac.jp>

Abstract

We found that a mountain appears taller when observed from a position that is higher than the mountain's height. Observers were first asked to look at photographs of mountains taken from various heights. They are then made to compare each of the photographs (standard stimuli) with the comparison stimuli, which comprised of images that had been digitally expanded or reduced in height as compared to the original photograph taken from a certain height. Subsequently, the observers selected one of the comparison stimuli where the height of the mountain in the standard stimulus appeared to be the same as that of the processed image. The results indicated that mountains appeared the tallest when they were observed from a height that was 1.4 to 1.7 times higher than their altitudes.

Although there are many studies on the perception of height, few studies have investigated how the perceived height of objects varies depending on the viewing height. In Bingham (1993), the participants were presented with photographs of trees, which measured 3 m to 27 m in height and which were taken from various heights. The participants were required to estimate the height of the trees. The results revealed that the perceived height of the trees was 2.7 m lower when viewed from a height of 4 m than when viewed from a height of 1.7 m. Can such an effect of viewing height on the perceived height of objects be observed even when the objects or other conditions of observation are different? Many a times, the impression of the same mountain in different photographs varies. Further, the perceived height of the mountain varies depending on the conditions surrounding the taking of the photographs, such as the position from which the photograph was taken, the direction from which sunlight fell on the mountain, and whether the mountain was covered with snow. Why do these factors affect the perceived height of the mountain? This study investigates the effect of viewing height on the perceived height of mountains by using images of mountains constructed using computer graphics.

In addition to the observation height, the 3D shape of the mountains was another factor manipulated in this study. Depth perception cues are crucial for the perception of 3D shape from a 2D display of objects. To investigate this point, we used two types of mountains (the mountains differed in terms of their shape). One was a cone-shaped mountain; the other, a barrel-shaped one. The cone-shaped mountain was almost the shape of a mathematical cone, while the barrel-shaped mountain resembled a laid barrel split into two. With respect to depth perception, the cone-shaped mountain sloped uniformly in all directions such that the observer could estimate, fairly precisely, the depth as well as the 3D shape of the mountain, from the ridgeline of its side. On the other hand, in the barrel-shaped mountain, the ridgeline was a poor indicator of the 3D shape of the mountain. We predicted that this difference in the ability to estimate the 3D shape would influence the perceived height of mountains in 2D images.
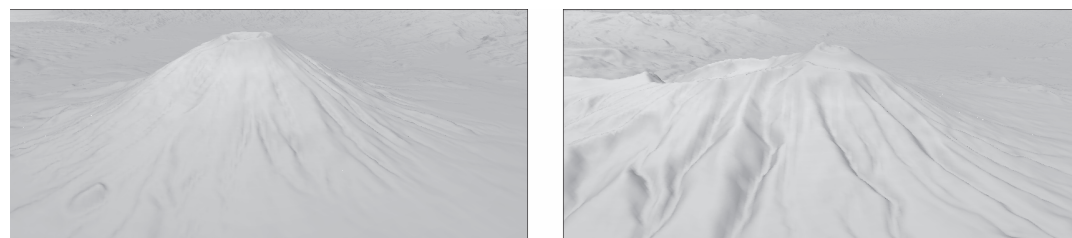
Fig. 1. Samples of the stimuli used in the experiment. To the left is the cone-shaped mountain (Mt. Yotei) and to the right is the barrel-shaped mountain (Mt. Iwate). These images were created by a CG software (Kashmir 3D) using the altitude database.

Method

Eight graduate and undergraduate students in the age group of 22–24 years, pursuing a course in human sciences at Osaka University (5 males and 3 females, $M = 22.75$ years, $SD = 1.04$), participated in the experiment in return for munchies worth a dollar. All of them had normal or corrected-to-normal vision and were naïve to the aims of the experiment.

The experiment was conducted using a Windows-operated personal computer (EPSON Endeavor MT-4500) with a liquid crystal monitor having a width of 36 cm and a height of 30 cm. The presentation of stimuli and the recording of the participants' responses were controlled by a program written by the authors, using Microsoft Visual Basic 6.0. The images of mountains as the stimuli were created using Kashmir 3D. Kashmir 3D is a free software used to generate 2D images of landscapes when a viewing point and line of vision are set by using databases of landscape altitude. This software can also simulate the reflection of the sunray, i.e., shading of the surface of the mountain, at a specific time and date. In this experiment, the altitude database, which lists altitudes at intervals of 50 m in the east-west and north-south directions and which is issued by the Geographical Survey Institute of Japan, was used.

The stimuli were 2D images of Mt. Yotei (Hokkaido Prefecture, Japan) and Mt. Iwate (Iwate Prefecture, Japan), which were created using Kashmir 3D. The samples of the images are shown in Fig. 1. Mt. Yotei was used as the cone-shaped mountain stimulus, while Mt. Iwate was used as the barrel-shaped mountain stimulus. The images simulated the situation where the mountains are observed from a point to the due south, at a distance of 6 km from the peak of the mountain, and the line of vision was to the due north. Since mountains generally do not have a distinct foot, i.e., the border between mountains and flatlands, the foot of a mountain was defined as the ground to the due south, at a distance of 3 km from the peak of the mountains. The mountains used in this experiment were located in inland regions; the peak of Mt. Yotei was experimentally defined as being 1350 m and that of Mt. Iwate was defined as being 1100 m. The simulated line of vision was the bisector of two lines—the line from the viewing point to the peak of the mountain and the line from the viewing point to the foot of the mountain. The 10 standard stimuli for each mountain were images viewed from the heights of 0.1, 0.3, 0.5, 0.7, 0.9, 1.1, 1.3, 1.5, 1.7, and 1.9 times of the height of each mountain. The 31 comparison stimuli for each of the standard stimuli were created based on the image viewed from a height of 0.1 times of the height of the relevant mountain (this being one of the standard stimuli). These original images were enlarged or reduced vertically at a ratio of 0.5 to 2.0 by a step of 0.05, and the surplus parts were trimmed. The set color of the surface of the mountains was a uniform green. The simulated condition of the position of the sun was at the culmination on the date of summer solstice. Each standard
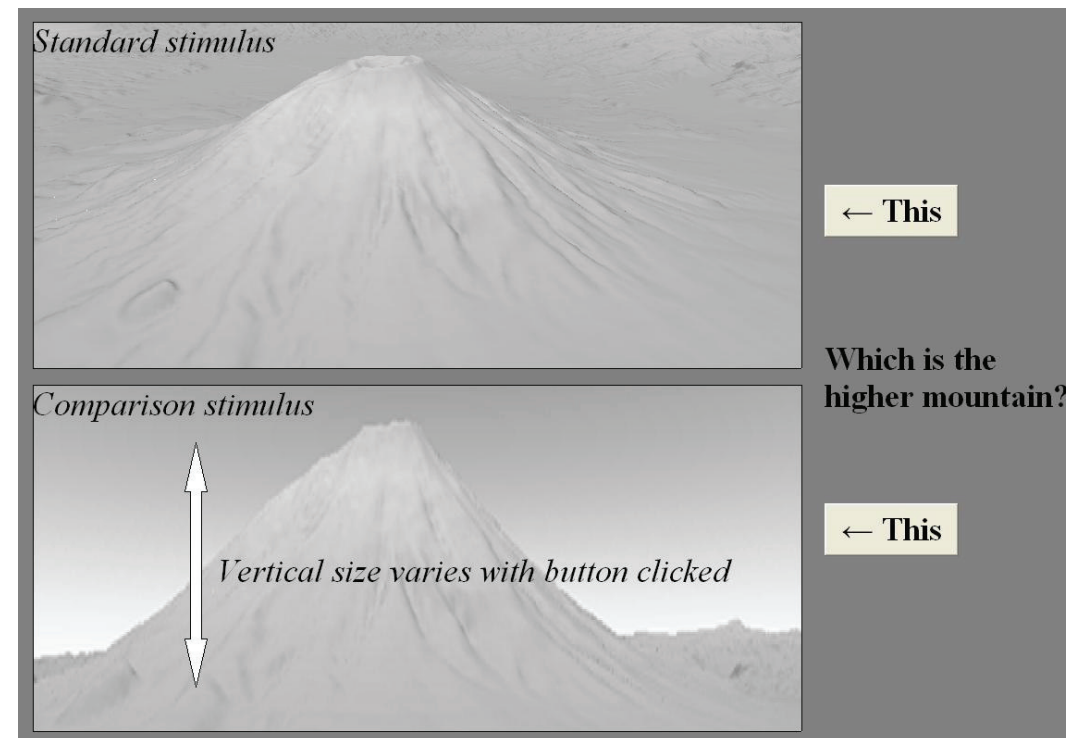

Fig. 2. Sample illustration of the screen in the experiment.

and comparison stimuli was 872 pixels in width and 375 pixels in height (30 × 15 cm on the screen). When a stimulus of this size is observed from a distance of 30 cm, the perspective of the scene becomes identical to the situation when the landscape is actually observed from the set viewing point and line of vision. The area surrounding the images was a uniform gray.

The experiment was conducted individually for each participant in a quiet room. No light from outside could enter the room, and it was illuminated with fluorescent lights. The participants sat facing the monitor such that by using a chin rest, the distance between their eyes and the center of the monitor was fixed at 30 cm. Further, the lines from the participants' eyes to the center of the monitor and the plane of the monitor were orthogonal. Next, the participants were given the instructions for the task. The experiment was conducted by using the method of limits. In the ascending series, the measurement started from the comparison stimulus in which the mountain was perceived to be clearly lower than that in the standard stimulus, and the height of the mountain in the comparison stimulus gradually increased. In the descending series, the measurement started from the comparison stimulus in which the mountain was perceived to be clearly higher than that in the standard stimulus, and the height of the mountain in the comparison stimulus gradually decreased. These starting points of comparison stimuli had been evaluated prior to the experiment by the different participants, none of whom participated in this experiment. The starting points were randomly selected from the comparison stimuli in the range of 0.5 to 0.65 in the ascending series and in the range of 2.35 to 2.5 in the descending series, in terms of the ratio of expansion or reduction of the vertical length of the comparison stimuli.

The experiment began with the participants clicking on the "start" button on the screen. In each trial, the standard stimulus was displayed at the top left of the screen, and the comparison stimulus was displayed at the bottom left of the screen, as shown in Fig. 2. In

addition, two buttons for selecting the stimulus were displayed at the right side of the screen. The participants clicked on the bottom button if they judged the mountain drawn on the bottom window (the comparison stimulus) to be higher. On the contrary, they clicked on the top button if they judged the mountain drawn on the top window (the standard stimulus) to be higher. The height of the mountain in the comparison stimulus decreased by a step of 0.05 (in terms of the ratio of enlargement or reduction of the image) every time the participants clicked on the bottom button, and the height increased by the step of 0.05 every time they clicked on the top button. When the button clicked by the participants changed from the bottom button to the top button, or vice versa, the subjective height of the mountain (the rate of enlargement or reduction) was recorded as the point of subjective equality, i.e., the point at which the height of the mountains in the standard and comparison stimuli became subjectively equal. Each trial ended when this change in the button clicked by the participants took place, after which the display for the next trial appeared. In consideration of the possibility that the participants might err in clicking the buttons, a "retry the adjacent previous trial" button was displayed at the bottom-right corner of the screen.

For each type of mountain—cone- and barrel-shaped—two blocks of 20 trials comprising 10 grades of observation height × 2 series (ascendant and descendent) were conducted for each participant. Therefore, the total number of trials conducted in the experiment was 80 (2 types of mountains × 20 trials × 2 repetitions). In each block, 20 types of trials (10 grades of observation height × 2 series) were presented in random order. The order of presentation of the mountain type was counterbalanced across the participants. The participants were allowed to rest for 2 minutes or more after each block of 20 trials. Prior to the experimental session, the participants underwent a practice session. In the practice session, with respect to each type of mountain, 10 types of trials comprising the standard stimuli of the five observation heights (0.1, 0.5, 0.9, 1.3, and 1.7 times of the mountain height) × 2 series were conduced once each in random order. Following the completion of the experiment, the participants were requested to answer a questionnaire regarding their sex, age, and whether and how they used the strategy for conducting the task required in the experiment.

Results

First, the mean perceived height of the mountains was calculated for each condition for each participant. The perceived height was defined by the ratio of expansion or reduction of the comparison stimuli. Fig. 3 indicates the grand means for each condition. The x-axis indicates the observation height, defined by the value of the height of the observation point divided by the height of the mountain peak, and the y-axis indicates the perceived height. A 2 × 2 within-subjects ANOVA was conducted for the mean values of the perceived height of the mountains, with the factors of mountain type (cone-shaped, barrel-shaped) and observation height (10 grades from 0.1 to 1.7 times of the mountain height with a step of 0.2). Mountain type ($F_{(1,7)}$ = 18.05, $p < 0.01$), observation height ($F_{(9,63)}$ = 25.08, $p < 0.01$), and the interaction ($F_{(9,63)}$ = 2.64, $p < 0.01$) between the two were all significant. With respect to this interaction, the simple effect of observation height was significant for both the cone-shaped mountain ($F_{(9,126)}$ = 11.65, $p < 0.01$) and barrel-shaped mountain ($F_{(9,126)}$ = 23.49, $p < 0.01$). In the case of the cone-shaped mountain, the mountain of the standard stimuli was perceived as being the highest when the viewing height was 1.7, and the barrel-shaped mountain was perceived as being the highest when the viewing height was 1.4. When the mountains were perceived as being the highest, the height of the cone-shaped mountain was perceived as being approximately 1.4 times of its actual height, and that of the barrel-shaped mountain was perceived as being 1.6 times of its actual height. The broken lines in Fig. 3 indicate the change in physical length between the peak and the foot of the mountain on the screen, where

the ratio against the length in the image simulating the condition in which the viewing height is 0.1 times of the mountain height.
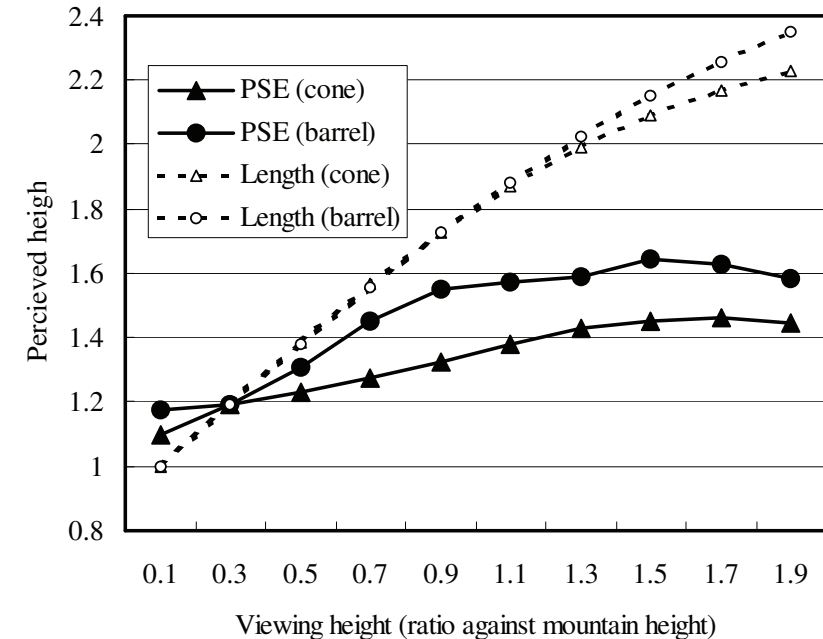

Fig. 3. The perceived height of the mountains in the 2D images as a function of viewing height. The broken lines indicate the length of the slope (from the top to the foot of the mountains) on the screen in terms of the ratio against the length for the stimulus with an observation height of 0.1 times of the mountain height.

Discussion

In this study, an experiment was conducted to investigate the effect of observation height on the perceived height of mountains by using computer graphics of mountains and the altitude database. The mountains were perceived to be the highest in the image simulating the observation height to be 1.4 times of the actual mountain height in the case of the cone-shaped mountain, and they were perceived to be the lowest in the image simulating the observation height to be 1.7 times in the case of the barrel-shaped mountain. When the simulated observation height was much higher than these points, the perceived height of the mountains decreased. This effect could be explained by the perception of the gradient of the frontal slope of the mountains. The higher the viewing point was, the longer the length of the frontal slope, i.e., the length from the point of the peak to the foot of the mountain, of the mountain on the 2D display was. This is illustrated by the broken lines in Fig. 3. This appears to relate somewhat to the perceived height of the mountain. In other words, the observers' estimation of the mountain height was influenced by the length of the frontal slope on the screen. However, it can be surmised that this effect was limited, considering the gap between the curves of the screen length and those of the perceived height, as shown in Fig. 3. In addition, the effect of the observation height was greater in the case of the cone-shaped mountain than in the case of the barrel-shaped mountain.

This finding implies that the observer can estimate the gradient of the frontal slope in a relatively precise manner for the cone-shaped mountain because of its regulated shape and, as a result, can estimate the height of the mountain. On the other hand, such an estimation of the slope was more difficult in the case of the barrel-shaped mountain because of its unregulated shape, resulting in a less precise estimation of the height of the mountain. However, this explanation is hypothetical, and should be examined by means of an experiment requiring the observers to estimate the gradient of the frontal slope of the mountain on 2D images. With respect to the estimation of the gradient of a slope, Gibson (1950) proposed that the gradient of a slope would be perceived to be less inclined than the actual gradient, while Creem-Regehr, Gooch, Sahm, and Thompson (2004) proposed that the perceived gradient would be perceived as being steeper than the actual gradient. Further research on the perceived height of mountains may provide a new interpretation for the controversy with regard to slope perception.

An individual's depth perception is based on oculomotor cues, binocular retinal disparity, motion-produced cues, and pictorial cues. In the perception of 2D static images, only pictorial cues can be used. Pictorial cues can be categorized into the gradient of texture, relative height of objects on images, relative size of objects, overlapping of objects, familiar size of objects, and shading. Wanger, Ferwerda, and Greenberg (1992) proposed that the cue of shade and light is the most prominent of the pictorial cues, for the perception of 3D objects. In this study, the simulated directions of the sunlight and the line of vision were accorded, i.e., the sunlight illuminated the mountains from the due back of the observer. In this case, the slope visible from the observation point was illuminated in a relatively uniform manner and, as a result, shade and light became extremely weak. If the cue of shade and light plays an important role in the estimation of 3D shape of objects, it is expected that when the cue of shade and light is exaggerated in simulated images of mountains, the perceived shape of the object as well as the perceived height of the mountain would become more precise. It would be interesting to conduct an experiment examining this prediction. In addition, depth perception differs depending on whether or not objects are displayed within a frame (Eby & Brounsyein, 1995). Moreover, the perception of objects' height is affected by the size of the frame (Dixon & Profitt, 2002). Moreover, it is expected that the estimation of the 3D shape of a mountain from a 2D display relates to various kinds of factors such as the texture of the mountain in the 2D images and the landscape surrounding the mountain. The findings obtained in this study should be investigated from a broader range of aspects of spatial vision.

References

Bingham, G. P. (1993). Perceiving the size of trees: Biological form and the horizon ratio. *Perception & Psychophysics, 54,* 485-495.

Creem-Regehr, S. H., Gooch, A. A., Sahm, C. S., & Thompson, W. B. (2004). Perceiving virtual geographical slant: Action influence perception. *Journal of Experimental Psychology: Human Perception and Performance, 30,* 5, 811-821.

Dixon, M. W., & Proffitt, D. R. (2002). Overestimation of heights in virtual reality is influenced more by perceived distal size than by the 2-D versus 3-D dimensionality of the display. *Perception, 31,* 103-112.

Eby, D. W., & Braunstein, M. L. (1995). The perceptual flattening of three-dimensional scenes enclosed by a frame. *Perception, 24,* 981-993.

Gibson, J. J. (1950). The perception of visual surfaces. *American Journal of Psychology, 63,* 367-384.

Wanger, L. R., Ferwerda, J. A., & Greenberg, D. P. (1992). Perceiving spatial relationships in computer-generated images. *IEEE Computer Graphics & Applications, 12,* 44-58.

TIME- AND SPACE-ORDER EFFECTS IN TIMED BRIGHTNESS DISCRIMINATION OF PAIRED VISUAL STIMULI

Geoffrey R. Patching, Mats P. Englund and Åke Hellström.
Department of Psychology, Stockholm University, SE-106 91 Stockholm, Sweden.
E-mail: grp@psychology.su.se

Abstract

Despite the considerable import of both response probability and response time for testing models of choice there is a dearth of chronometric studies of time- and space-order effects in discrimination of paired visual stimuli. In this study, systematic asymmetries in discriminating the brightness of paired visual stimuli are examined by way of binary response probability scaled in terms of log-odds ratios, as well as by signed response speed (i.e., the inverse of response time with the sign of the judged difference). For two stimuli separated by a time interval, psychometric and chronometric results revealed equivalent time-order effects, but simultaneous presentation with a spatial separation revealed no effects of space order. Implications of these findings for random walk and diffusion models of sensory discrimination are discussed.

Fechner (1801-1887) was among the first to discover that when two stimuli are presented for comparison people systematically overestimate the magnitude of one stimulus and underestimate the magnitude of the other. The term, time-order effect (TOE) is used to refer to such asymmetries in paired comparisons of stimuli separated by a time interval, and the term space-order effect (SOE) to asymmetries in comparisons of paired stimuli separated spatially. By convention, a positive effect is taken to refer to an overestimation of the first (or left) stimulus as compared to the second (or right) stimulus and a negative effect as an underestimation of the first (or left) as compared to the second (or right) stimulus.

In brightness discrimination, the TOE has been found to change from positive to negative with increasing inter-stimulus interval (ISI) from 1-9 seconds (Meada, 1959). Concerning the SOE, Kellogg (1931) reports a negative asymmetry in split-disk brightness discrimination, in that participants tended to choose the right-half more frequently than the left despite equally balanced brightness differences. Yet, in darkness discrimination of paired luminance gradients, participants tend to choose gradients with the darkest end on the left as compared to the right (Mattingley et al., 1994). So, there is some preliminary evidence to suggest that asymmetries in brightness discrimination are perceptual, but precisely what processes underlie them have yet to be fully determined.

Asymmetries in sensory discrimination are all too often dismissed as bias, which may appear as a result of prejudiced decision criteria (Allen, 1977), or verbal categorization of stimuli toward the mean of the stimulus series (John, 1975). Others envisage some kind of retention loss (Link, 1978) such that the activation induced by one stimulus is compared to a lower fidelity mental representation of the other. In regard to the SOE, similar appeals have been made by reference to known functional asymmetries in neural anatomy (Mattingley et al., 1994), noncentral fixation and scanning effects (Masin, & Agostini, 1991).

In the paired comparison of stimuli, bias is associated with the notion of an additive effect. For instance, Davidson & Beaver, (1977) extended the classic BTL model (Bradley & Terry, 1952; Luce, 1959) to predict the probability, p(A>B|A,B) of choosing A over B, given that A was presented first (or left), by inclusion of a constant order effect w, which is additive