Can we match the variance across different visual features?

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Abstract

"Sensibility to variation" is considered to be a significant cognitive mechanism for adaptive decision making and action. It has been demonstrated that humans as well as animals have the ability in many perceptual properties. Here we tested whether people can compare and match the variance across perceptual domain. We examined subjective equal levels of variance across different perceptual properties, size and orientation, using the method of adjustment. The size- and the orientation-adjustment tasks were conducted in a between-subjects design. The point of subjective equalities (PSE) of the three target set variance levels were obtained. The results indicate that observers could adjust the size variance according to the direction variance in the size-adjustment task and do the reverse in the direction-adjustment task, and that the relation between the variance magnitudes of the two domains is linearly related. The result implies that people can sense the magnitude of variability of set of items and match the magnitude across perceptual domains.

Keywords: variance representation, magnitude estimation, size, orientation, method of adjustment

Introduction

The ability to quantify variation, here designated as "sensitivity to variation," is of great importance for adaptive action. For example, categorizing objects requires knowing the extent of variation among those objects; adaptive decision making requires an accurate representation of the outcome variability; segregating signal from noise requires knowledge of the variation of signal and noise patterns. The "sensitivity to variation" is also significant when representing the uniformity or sameness of objects, events, and social behaviors. Many studies have pointed out that the discrimination of and sensitivity for stimulus variability affects both human and animal judgment and behavior (Neuringer, 2004; Payzan-LeNestour, Balleine, Berrada, & Pearson, 2016; Wasserman, Young, & Cook, 2004). Correspondingly, an intriguing possibility arises that the cognitive and neural substrates underlying variability discrimination may be common to a wide range of organisms.

Several studies performed in a psychophysical approach have demonstrated the human ability to discriminate orientation variance (Mansouri, Hess, & Allen, 2007; Morgan, Chubb, & Solomon, 2008), sound sequence variance (Byrne, Viemeister, & Stellmack, 2014), variance of facial expression (Haberman, Lee, & Whitney, 2015), and variance of action consequence (Ueda, Yakushijin, & Ishiguchi, 2015). Such studies used variance as an index to quantify the "extent of variation," since it provides a statistical measure of data dispersion. Taken together, the results from comparative, behavioral, and psychophysical approaches, lead to the assumption that humans and animals may evolve the ability to sense the "extent of variation" surrounding objects and/or events. This raises the question of whether "sensitivity to variation" is specific to the particular property of each system, or a property of a common system. Is it possible that "sensitivity to variation" exists across different visual features? Or is it a specific property of a particular visual feature? Relating variance perception to economical risk judgment, Payzan-LeNestour et al., (2016) tested whether after-effects would distort variance perception and found that the perceived variance decreased after prolonged exposure to high variance within a number of different visual representations. They demonstrated that these after-effects occur across different visual representations of variance (i.e., Bloomberg Line Plot and Balls-in-Buckets), suggesting that they are not sensory, but operate at a higher level of information processing. Such studies allow to predict that a distinctive mechanism may mediate variance representation, independently from the perceptual processes.

To further explore the possibility of a common mechanism for variance representation, we tested subjectively equal levels of variance across different perceptual properties, using the method of adjustment. We tested whether the point of subjective equality (PSE) of the target set would increase with an increasing variance of the adjustment set. We predicted that, if the common and distinctive variance representation systems mediated the variance perception of different properties, then the PSE of one perceptual set would change with the changes in the variance of the other perceptual property. Furthermore, a systematic relation would be predicted by examining the relation between variance size in a particular domain and the PSE in a different domain. In the present study, size and direction were selected as perceptual domains, as they have been well examined in variance tasks (Mansouri et al., 2007; Morgan et al., 2008; Tokita & Ishiguchi, 2015). We used illustrations instead of simple objects such as discs or Gabor patches, since objects in the natural world are multi-dimensional. We aimed to use the items of similar complexity, so that observers could easily understand the task requirements and attentively perform the adjustment task (Yang, Tokita, & Ishiguchi, 2018).

Experiment

Stimuli sets of two perceptual domains, size and direction, were used. For the size domain, a strawberry illustration was used, whereas for the direction domain, a lollypop illustration was used. Two types of adjustment tasks were conducted: a size-adjustment task and a direction-adjustment task. For the size-adjustment task, the target was a set of lollypops (i.e., direction domain) and the adjustment was a set of strawberries (i.e., size domain), whereas for the direction-adjustment task, the target was a set of strawberries and the adjustment was a set of lollypops. Two stimulus sets, a target and an adjustment set, were simultaneously presented on the display. Observers were asked to adjust the variance of the adjustment set so as to make it subjectively identical to that of the target set. The PSEs were obtained for each task. Prior to the adjustment task, the observers performed variance discrimination tasks for each perceptual domain, to ensure that they understood the requirements for the assigned adjustment task.

Methods

Participants The subjects were 38 undergraduate students from Mejiro University (19 females, 19 males), all of which presented normal or corrected-to-normal visual acuity. They were randomly assigned to one of two adjustment tasks (i.e., the size-adjustment or the direction-adjustment task), thus each task included 19 observers. All observers provided informed consent prior to participation, and they were not informed of the purpose of the study. This research was approved by Ochanomizu University's institutional review board.

Apparatus The experiment was conducted in a normally lit room. The stimuli were displayed on an iMac desktop monitor controlled by a Macintosh computer (Mac OS X). Stimuli presentation was controlled using Psychophysics Toolbox Version 3r (Brainard, 1997; Pelli, 1997) for MATLAB (Version 8.4, Mathworks, MA). The illustrations were created using PowerPoint 2016. Observers viewed the screen with both eyes, and they were seated approximately 60cm away from the screen.

Design The two tasks (i.e., the size-adjustment and direction-adjustment tasks) were conducted in a between-subjects design. We used the between-subject design for the purpose of minimizing the practice effect. In each adjustment task, the target set had three levels of variance size: squares of 10, 14, and 18° in the size-adjustment task and squares of 0.1, 0.16, and 0.22 of relative size in the direction-adjustment task. Prior to the adjustment task, the observers performed a size and a direction variance discrimination tasks to confirm their understanding of the adjustment task requirements.

Stimuli The sets of stimuli were created as previously described by Yang, Tokita, and Ishiguchi (2018). All stimuli were presented against a light gray background. The items were placed in a square cell with specific side lengths. The array was divided into a 4 × 3 matrix. Each cell subtended a visual angle of 1.16° × 1.16°, and the entire array subtended 5.56° × 6.25°. The items were arranged within the array, so that each item was displayed at the center of a cell. Regarding the size domain stimuli, the size of an item was defined by the square of the side length of the item. Henceforth, in this domain, side "length" is referred as "size", for simplicity. The mean item size within a set was represented as 1, and the size of each item within that set was expressed in relation to that mean size. Within each trial, all the presented items were scaled by a multiplicative factor to discourage the observers from basing their judgment on the previously viewed items. Four multiplicative factors were used, and within each trial all items were scaled with the same factor, which was randomly selected. Concerning the stimuli within the direction domain, the direction of the lollypop sticks varied. The original direction of the items was randomly selected from a range between －15° and 15° relative to the vertical direction.

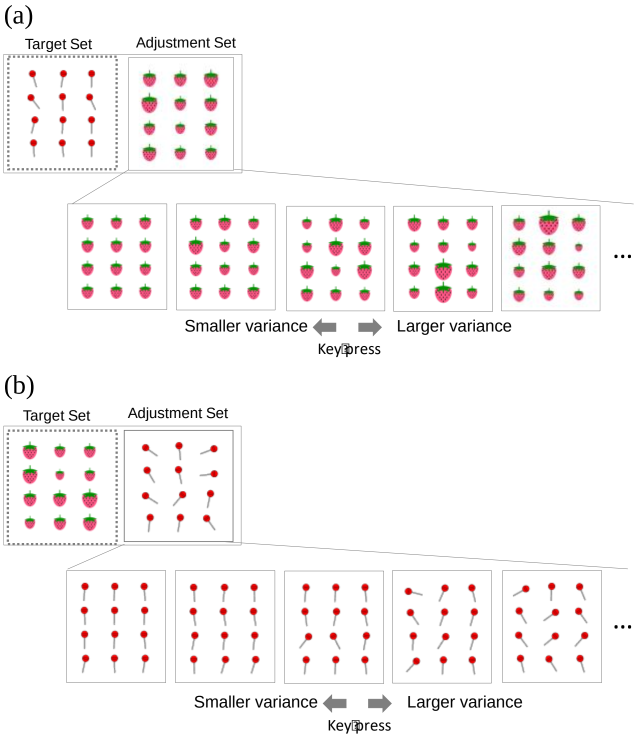


Figure 1: Schematic view of the experimental procedure for the size-adjustment task (a), and the direction-adjustment task (b).

To control the item set variance, a fixed variance generation method was used, in which the mean and SD of the samples randomly drawn from normal distribution was fixed to the expected value (Tokita & Ishiguchi, 2015; Yang et al., 2018). In the adjustment tasks, all of items in an adjustment set changed values according to random sampling from defined distributions when a subject pressed a key.

Procedure Each observer completed one 45-min session consisting of two blocks of variance discrimination task and two blocks of the adjustment task. First, the observer completed two types of variance discrimination, a size and a direction discrimination tasks, which consisted of eighty trials each. Stimuli and procedure of the variance discrimination tasks were same in the study by Yang et al. (2018); two set of stimuli, namely standard and comparison stimuli, were sequentially presented, both of which comprised 12 items. The array position of the standard and comparison sets was randomly changed; in half of the trials, the standard set appeared on the left side while the comparison set appeared on the right side, or vice versa. Each trial started with the display of a fixation cross for 500 ms followed by a blank screen for 400 ms. The first item set was presented for 240 ms. The second item set was presented for 240 ms after a blank screen for 600 ms, and then a blank screen was shown until a response was recorded. The next trial automatically began 500 ms after the response. Observers were asked to decide which item set in an array had a larger variance in size or direction. When they thought that the variance on the right array was larger than that on the left array, they pressed the “z” key, otherwise, they pressed the “c” key. The size variance of the standard set was fixed to a square of 0.14 and those of the comparison sets were squares of 0.17, 0.20, 0.23, and 0.26 in the size variance discrimination; the direction variance of the standard stimuli was a square of 13° and those of the comparison stimuli were squares of 16°, 19°, 22°, and 25° in the direction variance discrimination. A two-alternative forced choice procedure was used in the tasks. All parameters used in both tasks were decided on the basis of pilot studies.

Then participants performed two blocks of the adjustment task. Figures 1(a) and (b) show a schematic view of the stimulus presentations in each adjustment task. Two stimulus sets—a target and an adjustment set—were simultaneously presented on the computer monitor; the target set was presented on the left while the adjustment set was presented on the right. Each target set was kept presented while observers adjusted the magnitude of variance in the adjustment set. Observers were asked to increase or decrease the variance of the adjustment set to match that of the target set. The observers increased or decreased the variance by pressing the right- or left-arrow keys. Upon completion of the adjustment, the “c” key was pressed, followed by a presentation of fixation point on the computer monitor. When they were ready for the next trial, they were instructed to press the space bar.

Each block included three target set levels and 10 starting points for each adjustment set, and ten repetitions were performed per each target level. This resulted in 30 trials (3 variance levels × 10 starting points (5 ascending and 5 descending points)) per block. Each participant performed two blocks of the assigned adjustment task. Thus, for each target variance level, the PSE was obtained from the average of 20 data points. The variance levels and starting points were randomly presented in the block.

Analysis In the variance discrimination task, the correct rate corresponded to the performance measure. In the size adjustment task, the mean adjusted variance was calculated at each variance level.

Results

Two observers whose performance in either of the variance discrimination tasks was at the chance level, and one observer who did not follow the instructions in the adjustment task, were excluded from analysis. This resulted in a final sample size of N = 17 in the size-adjustment task and N = 18 in the direction-adjustment task. Figure 2 (a) and (b) show the mean PSEs in each variance level and for each adjustment task, respectively. The means of correct rates for the size variance and the direction variance discrimination tasks were 0.78 (SD = 0.06) and 0.77 (SD = 0.05), respectively.

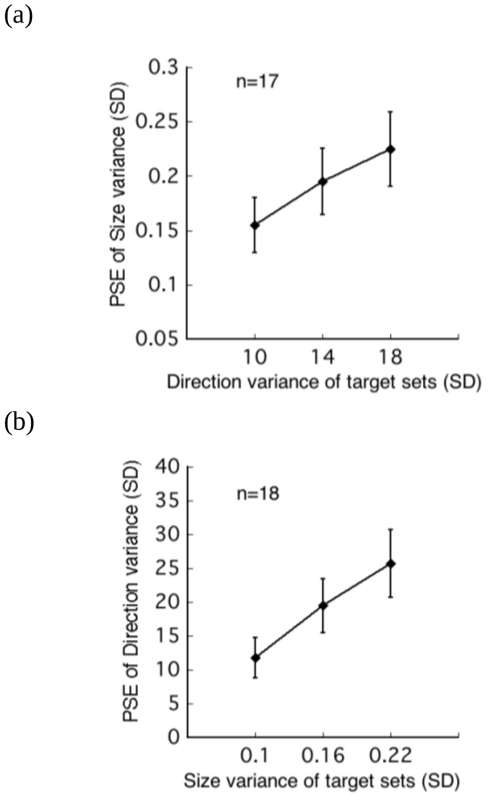


Figure 2: Mean PSEs of the adjusted size variance (SD) in the size-adjustment task (a), and Means PSEs of the adjusted direction variance (SD) in the direction-adjustment task (b). Error bars represent the standard deviation.

The results show that, in both tasks, the mean PSEs increased with the variance of the target level. In order to test whether the observer could represent the variance across different perceptual domains, we performed one-way repeated measures analysis of variance on the mean PSEs of each task. In the size-adjustment task there was a significant effect of the variance level on the mean PSEs (F (2,16) = 101.582, $p < .01$). A Bonferroni post-hoc analysis revealed a significant difference across variance levels ($p < .01$), suggesting that the PSEs of the adjusted variance differed across the target variance levels. Similarly, a significant effect of the variance level on the mean PSEs was found for the direction adjustment task (F (2,17) =142.38, $p < .01$). A Bonferroni post-hoc analysis revealed a significant difference across variance levels ($p < .01$), suggesting that the mean PSEs of the adjusted variance differed across target variance levels.

In order to directly compare the results of the size- and direction-adjustment tasks, we plotted the data from each observer on a graph (figure 3 (a)), and fitted a regression line to the data points, which revealed good correlation coefficients (i.e., ≥ 0.95). The slopes and intercepts of the regression were then obtained for each observer and for each adjustment task.

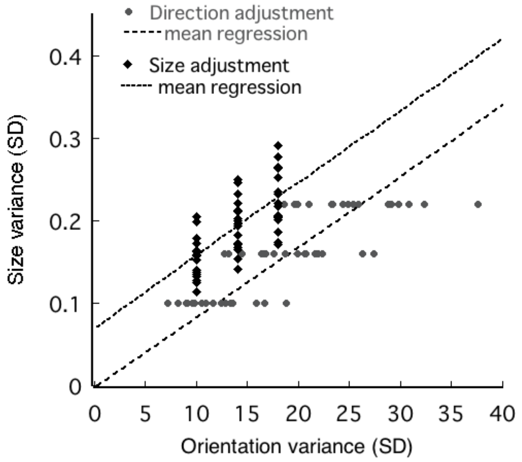
Figure 3(b) shows the mean slopes of each observer's regression function in the size- and direction-adjustment tasks, respectively. To examine the slope difference between the adjustment tasks, an independent-samples t-test was conducted for the mean slopes of each task. No significant differences were found ($t(33) = -0.531$, $p > .1$), suggesting that the single linear regression model could explain the relation between the size and the direction variance of sets. Furthermore, we performed a one-sample t-test to compare the mean intercepts of the direction-adjustment task with the intercept of 0, and found no significant differences ($t(17) = -0.922$, $p > .1$). Similarly, we carried out a one-sample t-test to compare the mean intercepts of the size-adjustment task with the intercept of 0, and found a significant difference ($t(16) = 6.841$, $p < .01$). This could be interpreted as a constant error of the size adjustment task. We discussed on the result further in the discussion section.

Discussion

To explore the possibility of a common and distinctive mechanism for variance representation, we examined whether and how the extent of variation of a specific perceptual property could be represented in relation to different perceptual properties. Two types of tasks, the size- and the direction-adjustment tasks, were conducted in a between-subjects design. To control the variation of the stimuli set, we used the variance of a set of items. The PSEs of three target variance levels were obtained using the adjustment method. The results indicate that the observers could represent the direction variance to the subjectively equal point of the size variance, and that the relation between the variance magnitudes of the two domains is linearly related. Specifically, observers could adjust the size variance according to the direction variance in the size-adjustment task and do the reverse in the direction-adjustment task. To test the relation between the two tasks, we compared the mean slopes of the linear regression functions between the two tasks, and found that the slopes did not differ between the size and direction-adjustment tasks, demonstrating that people can sense the magnitude of variability of set of items and match the magnitude across perceptual domains.

We also found that the mean of intercepts of the size-adjustment task was significantly higher than 0, which could be interpreted as a constant error of the adjustment task; the variance of the target set (i.e., direction variance) showed bias toward overestimation in relation to the variance of the adjustment set (i.e., size variance) or the variance of the adjusting set (i.e., size variance) showed bias toward underestimation in relation to the variance of the adjustment set (i.e., orientation variance) . Neither explanation, however, consistent with the result that there is no bias in the direction-adjustment task since both tasks involved the perception of size and direction variance. Further investigation is necessary to clarify the phenomenon.

(a)



(b)

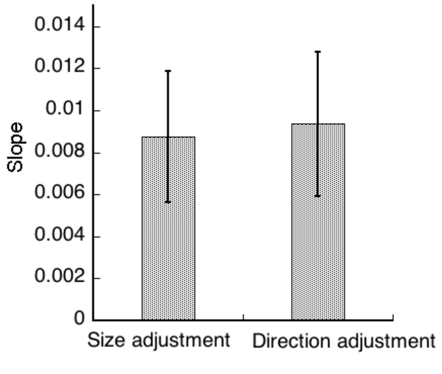


Figure 3: Data from each observer in the size- and direction-adjustment tasks. The dotted line is the regression function of

each task's mean PSE (a). (b) shows mean slopes of each adjustment task. Error bars represent the standard deviation.

It is intriguing that consistent slopes were observed even in the between-subjects design. The results suggested that single linear regression model could explain the relation between the size and the direction variance of sets. Taken together, with the findings of Payzan-LeNestour, et al.(2016), which indicated the after-effects that exist across the variance in different perceptual domains, our result implied that people sense the magnitude of variability of an item set according to a common system, independent of the perceptual property. The results support the claims of previous studies.

How are observers able to match the variance of size with that of direction? Is there a particular strategy or is variance matched only by intuition? When the observers were asked to match the variances, they commented that it was difficult and they could not figure it out. However, the results showed otherwise. Some point out that they performed the task by intuition, while others point out that they used their sensitivity to magnitude of variance in each stimuli domain to compare and match the magnitude while performing the task. It may be that the extent of outlier could be used for evaluating the variance of each perceptual domain, and the evaluated magnitude could be used for the matching of the variance across stimuli. We need to examine how the variance is extracted from various visually distinctive features. Did the subjects truly use the variance information in performing tasks (Tokita, Ueda, & Ishiguchi, 2016), or did they use some sort of proxy to represent variance? For example, Lau & Brandy (2018) pointed out that range of the items were utilized as proxies for representing the variability of set items. If the participants using some sort of proxy to represent variance and translate that into "mental magnitude", then a domain-general mechanism for variance may not be necessary.

Further research is necessary to examine the characteristics and the processes of "the sensitivity for variation" in human observers. First, the claim for linearity is not so robust since only a three pointe were collected. It is necessary to collect more points using the wider range of variance in target variance both area size and orientation domain. Second, we need to test whether variance matching is possible across a variety of stimuli sets, such as facial expressions, object shapes, object speed, and action consequences. Third, it is necessary to devise a common metric to measure the magnitude of variability. Variance—the measurement of variation used in this experiment—is an effective index of variation, but insufficient when directly comparing the variation of different perceptual properties such as size and direction. Entropy or relative entropy in information theory may be a useful index for variability; for example, Young and Wasserman (2001) involved relative entropy as a degree of categorical variability to assess the accuracy of classification of the levels of visual display variability to demonstrate that people use entropy to classify the levels. Fourth, it would be effective to test whether training for variance discrimination of a particular perceptual property could be extrapolated for variance discrimination of a different property. It is predicted that if variance estimation is mediated by a common system, then the training effect on one perceptual property should transfer to different properties.

In summary, this study tested whether people could match the magnitude of variance between size and direction involving the method of adjustment. The results indicated that people could match the variance across the property and that the relation between the variance magnitudes of the two domains is linear, implying the possibility of a distinctive cognitive process for "sensitivity to variation" independent of the perceptual property.

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