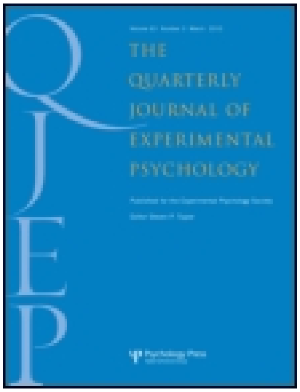

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Short article

Priming by the mean representation of a set

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Recent evidence suggests that sets of similar objects can be represented in terms of their statistical parameters, such as mean size. Observers are more likely to indicate that a probe item was part of a previously presented set of items when the probe has the same size as the mean size of the set than when it has the same size as one of the set members (e.g., Ariely, 2001). Here we provide further evidence for set representation by statistical properties, by showing priming by the mean size of a set of circles. Observers were presented with a set of circles followed by a degraded outline of a single target circle and were asked to judge the contrast of the target. Target contrast was reported to be significantly higher when the target circle had the same size as the mean size of the preceding set of circles than when it had the same size as one of the members of the preceding set. These findings show that conceptual priming by a summary description can be stronger than exact repetition priming.

Keywords: Statistical processing; Size; Mean; Priming; Perceptual representation.

When the visual system is presented with a set of simultaneously presented similar objects, previous research has suggested that a statistical summary of the set (for example, the mean) is held instead of a representation of the individual members (Ariely, 2001; Chong, Joo, Emmanouil, & Treisman, 2008; Chong & Treisman, 2003, 2005a, 2005b; De Fockert & Marchant, 2008; for similar findings with sequential stimulus presentation, see Crawford, Huttenlocher, & Engebretson, 2000). This summary, such as the mean size of the set, has been shown to be estimated to a relatively high degree of accuracy compared to member judgements (Ariely, 2001). Moreover, discriminations between sets on the basis of mean size can still happen with minimal detriment after memory delays of up to two seconds (Chong & Treisman, 2003). These findings have been interpreted to suggest that when processing sets of multiple objects, the visual system does not represent each item the way it does a single item, but instead represents the entire set in terms of a summary representation. However, recent findings have demonstrated that an alternative mechanism by which only a subset of items is sampled could be used in order to compute a mean statistic (Myczek & Simons, 2008; Simons & Myczek, 2008; see also De Fockert & Marchant, 2008).

The current study was set up to provide further evidence that a set of multiple objects can be

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represented in terms of its statistical parameters. We argued that, if processing multiple objects leads to the formation of a statistical description of the entire set, then processing of subsequent items that share characteristics with the summary description should be facilitated. Importantly, this facilitation effect by the summary description should be greater than facilitation by an actual member of the previously perceived set. In order to test this prediction, we measured the existence of a summary representation of the set by both direct and indirect means. The direct method was to present observers with sets of objects with different sizes and to ask them to estimate the mean size of the set. At the end of each trial, the accuracy of their estimation was measured in a two-alternative forced-choice task. This method has been used repeatedly before (e.g., Chong & Treisman, 2005a; De Fockert & Marchant, 2008), and observers show reasonable to good ability to estimate mean set size.

The novel aspect of the current study is the use of an indirect method to measure the existence of a summary representation of the set. To this end, we adapted the priming paradigm developed by Merikle and Reingold (1991). In these experiments, participants were briefly shown a pair words, one of which was cued with arrows. Next, a single target word was presented against a noise background mask that degraded the appearance of the word. The direct method to measure priming by the previous display involved asking participants to indicate whether the target word had been presented before. This method revealed priming for cued prime words, but not for uncued prime words. In the indirect method, participants were asked to report whether there was a high contrast or a low contrast ("easy to see" or "hard to see") between the target word and the noise background mask. Critically, the indirect method revealed priming for uncued prime words.

Merikle and Reingold (1991) developed their subjective contrast measure based on the finding that subjective perceptual experience can be affected by the contents of memory (Jacoby, Allan, Collins, & Larwill, 1988). Jacoby and Dallas (1981) had earlier reported a similar effect—namely, that the subjective duration of briefly presented masked words was longer for old than for new words. In the current study, we used this previous evidence to argue that if processing a set of multiple objects leads to the extraction of a summary description of the set, then this extracted representation should influence participants' subjective experience of the perceptual contrast between a subsequently presented object and a background mask. Specifically, we predicted that processing of an item that matches the summary description should be facilitated to a greater extent, leading to a subjective experience of greater perceptual contrast, than would processing of a similar item that does not match the summary description of the previous set.

Participants were shown sets of circles of different sizes and were asked to estimate the mean size of the set. They then were given a task measuring subjective perceptual contrast similar to that used by Merikle and Reingold (1991), but this time presenting a target circle superimposed on a noise background mask. They were asked to indicate whether there was a high contrast or a low contrast between the circle and the mask. The size of the target circle could be either the same as the mean size of the previous set or the same as one of the members of the set. On the basis of previous evidence that exact repetition of an item tends to lead to substantially greater priming than priming on the basis of conceptual similarity between a prime and a probe (e.g., Roediger & Challis, 1992), one may predict that a target circle that repeats the size as one of the members of the previous set would be judged as being easier to perceive than a target circle whose size is different to all members of the previous set. However, we made the strong prediction that, if the perceptual representation of the set relies heavily on a summary description in terms of mean size, then the contrast between a target circle with the same size as the previous set mean and its background should appear greater than the contrast between a target circle with the same size as a previous member and its background. In other words, we predict greater conceptual priming[1] by the mean size of the set than repetition priming by one of its members.

Method

Participants

A total of 13 undergraduate students (2 males; age range, 18–40 years; mean age, 22 years) from Goldsmiths, University of London participated in exchange for course credit. All had normal or corrected-to-normal vision.

Materials and procedure

All stimuli were presented in grey on a black background (unless stated) on a 17″ monitor, connected to a PC running E-prime software (Schneider, Eschman, & Zuccolotto, 2002). Participants were seated so that the eyes were approximately 70 cm from the screen. Each experimental trial consisted of three stages: the presentation of a set of circles, the mean size of which observers were instructed to estimate and maintain until the end of the trial, followed by a degraded outline of a single target circle, in response to which observers made a contrast judgement. Finally, the accuracy of the estimated mean set size was measured by asking observers to choose which one of two circles had the same size as the mean of the set for that trial.

Each experimental trial began with a fixation cross presented for 500 ms in the centre of the screen. This was followed by the set of circles presented for 1,000 ms. Each set consisted of 8 differently sized outline circles (line thickness 2 pixels). The 8 set circles were taken from a larger set of 11 circles. The middle 3 circles were not included in the set of 8, as the mean could not be included because this would have prevented us from assessing subsequent conceptual priming without repetition. The 2 circles with sizes on either side of the mean were used at the end of the trial to measure observers' mean estimations and could not be included in the set to avoid observers having to make a mean versus member choice in the mean estimation task. Therefore, each set consisted of 4 circles that were smaller than and 4 circles that were larger than the set mean. The approximate difference between consecutive circle sizes in a set subtended 0.10° of visual angle. There were two types of set. Small sets had circle diameters of 0.9°, 1.0°, 1.1°, 1.2°, 1.6°, 1.7°, 1.8°, and 1.9°, with mean diameter of 1.4°. Large sets had circle diameters of 1.1°, 1.2°, 1.3°, 1.4°, 1.8°, 1.9°, 2.0°, and 2.1°, with a mean diameter of 1.6°. The circles were presented in randomly chosen locations in an imaginary 3 × 3 matrix, which was centred on the screen measuring 10.8° by 10.8°. Within each square matrix cell, a set circle was presented in one of the four quadrants of the cell in order to give the array a less regular appearance. The centre cell was never occupied.

Following a 500-ms blank screen, the display containing the target circle was presented for 2,500 ms. This display consisted of a white square centred on the screen measuring 2.4° × 2.4°. We added noise to the white square with Adobe Photoshop 5.5, by using a Gaussian monochromatic noise filter (noise value 100). Eight unique masks were constructed in this way. Superimposed on the noise background, an outline of a circle (line thickness 1 pixel) was presented in white. Although there should not have been any overall differences in contrast between the circle and the background across different masks, random local variations between the background masks ensured that participants readily accepted the suggestion that the displays varied in terms of contrast and that it was their task to classify them. The mean size of the set and the size of the target circle were manipulated in a factorial design, so that a small or large target circle was equally likely to be preceded by either a set with small or one with a large mean size. Moreover, for trials on which target circle size was different to the mean size of the set (i.e., a

[1] We use the term conceptual priming to differentiate it from exact repetition priming and to suggest that the resultant priming is due to the existence of an abstract concept of the set rather than exact repetition of one of its members. This is somewhat different from the standard usage of conceptual priming, which is normally related to priming after semantic processing.

small set followed by a large target, or vice versa), target size was the same as the size of one of the members of the set. Therefore, target circle sizes after the small set could be 1.4° (mean) or 1.6° (member), or 1.6° (mean) or 1.4° (member) after a large set. Participants were told that the contrast between the circle and the background varied from trial to trial and that they had to indicate whether they thought the circle had high contrast (the circle was easy to see) or a low contrast (the circle was hard to see). Responses were to be made while the display was on the screen, by pressing "z" or "x" with the left index and middle fingers. Mapping of high/low responses to the response keys was counterbalanced between participants, and no feedback was given.

Following the contrast discrimination task, two test circles were presented 1.5° to the left and right of the centre of the screen for 2,000 ms. The size of one of the test circles matched the arithmetic mean size of the diameters of the previous set; the other circle was either 0.10° smaller or 0.10° larger than the set mean. Neither of these circles was ever a member of the previous set. The circle with the mean size of the preceding set was equally likely to occur in the left or the right position and was equally likely to be accompanied by a smaller or a larger circle. Participants used their right index and middle fingers to press "1" (left) or "2" (right) on the number key pad to indicate which of the test circles (left or right) they thought had the same size as the mean of the previous set. Participants received feedback in the form of a short high-pitched tone if they chose the incorrect test circle or did not respond within a 2,500-ms response window. The next trial was presented after a 500-ms blank screen.

Each participant received four experimental blocks containing 32 trials each. The different conditions were intermixed within the blocks. To ensure adequate ability on both tasks, participants first completed four blocks of 32 practice trials each, in which they saw the set of circles followed by the test displays (i.e., without the contrast discrimination task) and were instructed to indicate which test circle they thought had the same mean size as the previously seen set. Following this, the contrast discrimination task was practised until the participants were comfortable with the task (no participant took more than 20 trials).

Results

On the mean judgement task, overall mean estimation accuracy was low (.53), but was significantly above chance: one-sample t test with test value = .50; $t(12) = 2.36$, $SEM = 0.014$, $p < .05$. When we used the same mean estimation task in the past, we obtained similarly low overall levels of accuracy (De Fockert & Marchant, 2008).

For the principal analysis, the proportion of "high-contrast" responses on the contrast discrimination task was entered into a 2 (mean set size: small vs. large) × 2 (target circle size: small vs. large) repeated measures analysis of variance (ANOVA), with participants as the random factor (see Figure 1). There was a nonsignificant main effect of mean set size, $F(1, 12) < 1$, suggesting that the proportion of "high-contrast" responses was statistically equal following sets with a large mean size (mean = .478, SE = .013) and following sets with a small mean size (mean = .474, SE = .014). There was no main effect for target circle size, $F(1, 12) < 1$. The proportion of

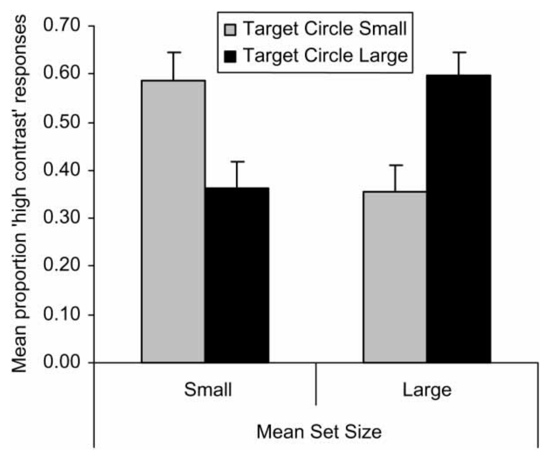

Figure 1. *Mean proportion of "high-contrast" responses on the contrast discrimination task as a function of target circle size and mean set size. Error bars indicate standard error of the mean.*

"high-contrast" responses was statistically equal for small target circles (mean = .470, $SE = .012$) and large target circles (mean = .482, $SE = .015$). Importantly, however, there was a significant interaction between mean set size and target circle size, $F(1, 12) = 4.78$, $MSE = 0.699$, $p < .05$. Following a set with large mean size, the proportion of "high-contrast" responses was greater for a large target circle (mean = .599, $SE = .045$) than for a small target circle (mean = .356, $SE = .053$); $t(12) = 2.35$, $SEM = 0.103$, $p < .05$. Conversely, following a set with small mean size, the proportion of "high-contrast" responses was greater for a small target circle (mean = .585, $SE = .060$) than for a large target circle (mean = .364, $SE = .055$), although this difference was only marginally significant, $t(12) = 1.97$, $SEM = 0.112$, $p = .072$.[2]

There were no significant effects for response latencies; however, speed of responding was not emphasized to the participants.

Discussion

After having seen a set of circles with different sizes, observers reported that the contrast between a target circle and a background mask was higher when the target had the same size as the mean size of the preceding set than when it had the same size as one of the members of the set. In line with previous evidence (Ariely, 2001; Chong & Treisman, 2003, 2005a, 2005b; De Fockert & Marchant, 2008), these findings suggest that observers can reliably extract the mean size of a briefly presented set of objects. Moreover, the mean representation of the set was able to prime perception of a subsequent object, by increasing the subjective contrast when the object matched the summary representation of the set. Since our design did not include a true baseline condition, in which no aspect of the set of circles was repeated in the target circle, we can only pit the level of priming by the mean representation against that produced by the repetition of a member of the set. Remarkably, however, conceptual priming by the mean representation of the set was still greater than repetition priming by one its members.

We first have to consider an alternative explanation for our findings—namely, that the observed effects reflect a bias towards responding consistent with the mean size of the set. If so, observers would decide whether a set had a small or large mean size and subsequently base their final estimation judgement on whether they categorized the set as small or large. This process is different from the suggestion that the set was represented in terms of the mean size, as it suggests that the results could be obtained without any accurate knowledge of the mean size of the set. Although this explanation may be valid for explaining performance on the final mean judgement task, we think it less likely to account for the priming effects on the contrast discrimination task. In this task, size was not a relevant feature, as it involved making a decision on the perceived contrast between a target circle and its background. No overt responses were made on the basis of the size of the target circle, and we therefore argue that the observed priming effects on subjective perceptual contrasts were unlikely to be due to a response bias towards either small or large items.

Instead, we interpret these findings as further evidence for representation of visual information in terms of statistical parameters. After viewing a set of similar items with different sizes, subjective perceptual contrast judgements suggest that perceptual representation of the set is based on its mean size. Not only were participants able to reliably estimate the mean size of a set of previously seen circles, their subjective perception of a single target circle showed greater priming on the basis of the mean

[2] We also ran the principal analysis including only trials on which participants made correct mean estimations. This analysis showed the same pattern of results, and this time both pairwise comparisons were statistically significant: Following a set with small mean size, the proportion of "high-contrast" responses was greater for a small target circle (mean = .53, $SE = .065$) than for a large target circle (mean = .30, $SE = .047$), $t(12) = 2.19$, $SEM = 0.105$, $p < .05$. Conversely, following a set with large mean size, the proportion of "high-contrast" responses was greater for a large target circle (mean = .62, $SE = .049$) than for a small target circle (mean = .37, $SE = .055$), $t(12) = 2.66$, $SEM = 0.097$, $p < .05$.

size of the set, rather than the size of one of its members. This conclusion is in line with two recent findings that also show that the mean size of a set of circles can implicitly influence size discriminations (Treisman, 2006). First, speeded same–different judgements of two circles were faster when one of the circles had the same size as the mean of a preceding set than when it had the same size as one of its members or a new item. Second, in a visual search task participants made more false alarms if the mean size of the search display matched the absent target. These findings suggest implicit priming by the mean size on judgements involving size. Our results show a similar effect on a task in which size is not a relevant feature.

Until recently, the proposed mechanism underlying the evidence for set representation involved processing the statistical properties of the entire set (Ariely, 2001; Chong et al., 2008; Chong & Treisman, 2003, 2005a, 2005b). However, a recent alternative explanation proposes a strategy that involves making a mean judgement on the basis of a small subset of items (Myczek & Simons, 2008; Simons & Myczek, 2008). On this view, observers use a strategy that does not involve extracting the mean of the entire set, but instead select a small subset of the set items to base their mean estimation on. Myczek and Simons (2008) have shown that actual performance was closely approximated by a simulation in which a subset of items was randomly selected, and mean judgements were made by comparing the test item with the mean of the selected subset. Certainly, we previously found evidence that did not support a strong whole-set averaging explanation, in which the mean representation is equally based on all set items (De Fockert & Marchant, 2008). After directing attention to one particular item in the set, mean estimations were shifted towards the size of the attended item and away from the whole-set mean. In terms of subset averaging, this may be interpreted to suggest that the attended member had an increased probability to be included in the subset. However, the results can be explained in terms of a flexible version of whole-set averaging using a mechanism of flexible weights, so that the value of an attended set member can influence the set mean disproportionately.

The present study was not designed to distinguish between the whole-set and subset averaging explanations, and our results can be explained with relative ease in terms of either mechanism. The finding that the priming effect was consistently greater when the target circle had the same size as the mean of the entire previous set may suggest that observers had based their summary representation on the entire set. However, as shown in the simulation work by Myczek and Simons (2008), the same mean estimation performance as that for human observers who are instructed to average the entire set can be obtained from a model averaging a smaller subset. Explanations in terms of whole-set averaging or subset averaging differ principally in terms of what proportion of a seen set a summary representation is based on, not in terms of what the eventual representation consists of. Consequently, these explanations would make the same predictions with regard to the present priming effects.

In summary, we compared exact repetition priming by a repeated member of a set of circles with conceptual priming by the mean set size. Regardless of the actual size of a target circle, whose contrast with its background had to be judged, a target circle was reported easier to perceive when its size was the same as the mean size of the preceding set than when it was the same as the size of one of the set members. These results suggest that sets of multiple items can be processed in terms of a summary representation and that this representation is capable of affecting subsequent perception as a function of whether an object shares characteristics with the extracted representation.

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