Bayesian inference underlies contraction bias

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In magnitude estimation tasks, participants tend to overestimate the physical magnitude of small variables and underestimate the magnitude of large ones, an illusion known as ‘contraction bias.’ Although contraction bias was discovered a century ago, the computational principles underlying this bias in estimation have remained unclear. We investigate this question in the framework of Bayesian inference.

In order to study the bias, participants performed a two-alternative forced-choice task in which they judged whether the length of a memorized bar (L_1) was longer than that of a second bar (L_2). Contraction bias was demonstrated by analyzing choice behavior in trials in which the lengths of the first and second bars were equal. In these impossible trials, subjects frequently reported short L_1 bars to be longer, and long L_1 bars to be shorter than their veridical lengths (Fig. 1, circles). We show that this bias is consistent with the performance of an ideal observer who uses Bayesian inference to incorporates a noisy representation of the memorized L_1 bar with the prior distribution of the bar lengths.

The hypothesis that contraction bias results from Bayesian inference yields two predictions. First, the bias is independent of the physical range of the stimuli. Second, increasing uncertainty in the memory of L_1 is expected to increase the reliance of its estimate on the prior distribution and therefore enhance the contraction bias. The first predication is confirmed by showing that contraction bias is not significantly different between two groups of subjects who were tested using different uniform distributions (Fig. 2, blue circles and black squares). In order to test the second prediction, we modified the task such that on selected trials, a secondary task had to be performed between the presentation of the first bar and the second bar, thus increasing the uncertainty in the representation of the memorized L_1 bar. As predicted, contraction bias was enhanced in the trials associated with the secondary task (Fig. 3, red squares). Thus we conclude that contraction bias results from Bayesian inference in which a noisy measurement is combined with a-priori knowledge about the distribution of magnitudes in order to improve performance.

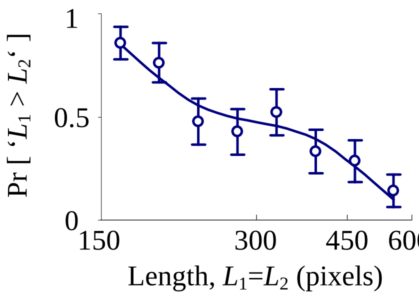

Figure 1: Contraction bias. Circles, fraction of times one subject reported L_1 as longer than L_2 in impossible trials, as a function of logarithmic bar length. Line, Bayesian Prediction.

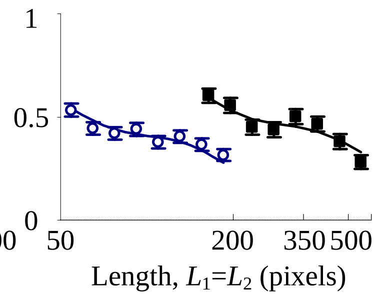

Figure 2: Shifting the prior results in a horizontal shift of the bias curve. Circles, range 50-200 pixels. Squares, range 150-600 pixels. Line, Bayesian prediction.

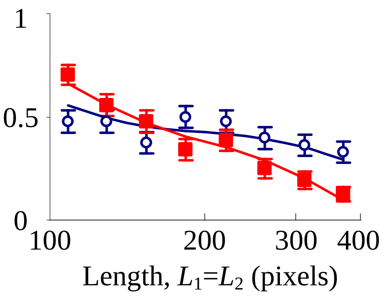

Figure 3: Adding noise to memory increases the slope of the bias curve. Circles, standard trials. Squares, trials with a secondary task. Line, Bayesian prediction.