

An Exception to Weber's Law in Numerical Representations by Rhesus Macaques (*Macaca mulatta*)

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INTRODUCTION

This experiment builds on previous numerical research with nonhuman primates. Results from previous numerical matching-to-sample tasks show a robust end effect at both ends of the stimulus continuum and an influence of relative continuum position. This task further examines the contributions of absolute numerical value and position in the stimulus continuum to numerical representation in nonhuman primates.

QUESTIONS

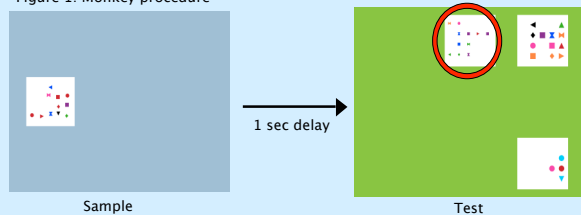
- What is the effect of continuum magnitude on performance?
- How does position of a numerosity within a continuum affect performance?
- Do our results conform to Weber's Law?

PROCEDURE

Two monkeys, Augustus and Spike, were trained on this task. Both monkeys had previous experience with a numerical matching-to-sample task with the stimulus ranges 1-9 and 1-15. Monkeys were run daily in experimental chambers housed in isolated sound attenuated booths. Each booth contained a touch sensitive video monitor and an automatic pellet dispenser. Subjects were monitored via a closed-circuit video system. Each touch sensitive monitor was connected to a iMac G5 that presented all of the stimuli and recorded the accuracy and the RT data of each response. Correct responses were followed by a banana-flavored food pellet, a change in the color of the monitor, and a distinct sound. Incorrect responses were followed by a different distinct sound and a 4 second time out during which the screen was dark. The sample was shown in a random location on a blue background. Touching the sample extinguished it, and following a one second delay, the test screen displayed the target and distractors on a green background (Figure 1).

The numerical values of the sample and distractors were chosen randomly. Stimuli were composed of geometric figures that differed in size, shape, and color. Cues including shape, color, element configuration, cumulative surface area, and element density were eliminated to ensure reliance on numerosity rather than secondary cues. Additionally, stimulus elements were heterogeneous in color and shape. Monkeys were tested with three stimulus continua: values 1-11 followed by values 3-13 and 5-15. The order of the continua 3-13 and 5-15 was counterbalanced across subjects. Data from the first 20 days at each range are shown.

Figure 1: Monkey procedure



RESULTS

Accuracy

Monkeys were tested with the stimulus ranges 1-11, 3-13, and 5-15. Accuracy for each of the 3 ranges is shown in Figure 2. When the stimulus ranges are plotted to equate the position of numerosities within the range (as opposed to the absolute numerosity), the accuracy functions differ significantly both qualitatively and quantitatively. Accuracy to end values at both ends of the continuum reflects a robust end effect. In addition to an end effect, accuracy also demonstrates a strong distance effect. Accuracy by the numerical distance between the target and the nearest distractor is shown in Figure 3.

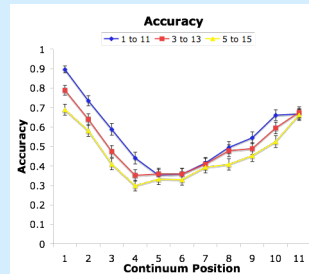


Figure 2: Accuracy by position in continuum. Bars reflect standard errors.

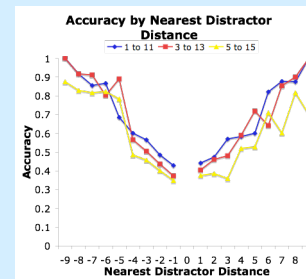


Figure 3: Accuracy by target-nearest distractor distance. Bars reflect standard errors.

RT

Reaction times to the sample are shown in Figure 4. Reaction times are significantly different between each of the 3 conditions, but do not increase with magnitude and show no effect of target numerosity. Median RTs for correct responses at test are shown in Figure 5. Reaction times at test are significantly different between each of the 3 conditions, and are longer for intermediate values, again suggesting magnitude and end effects.

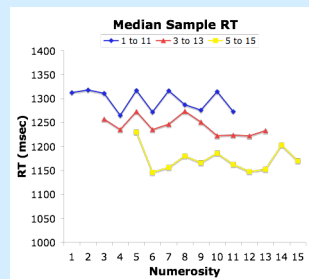


Figure 4: Median RT to sample. Bars reflect standard errors.

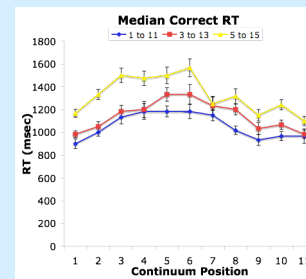


Figure 5: Median RT for correct responses at test. Bars reflect standard errors.

Response Variation

Standard deviations for responses (Figure 6) do not increase with magnitude. While the standard deviation values are different among our 3 ranges, the shapes of the functions are qualitatively similar. The coefficient of variation, calculated by dividing the standard deviation of responses at each numerosity by the mean response at that numerosity, is shown in Figure 7. All 3 COV functions have a negative slope.

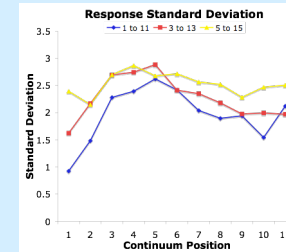


Figure 6: Standard deviation of response. Bars reflect standard errors.

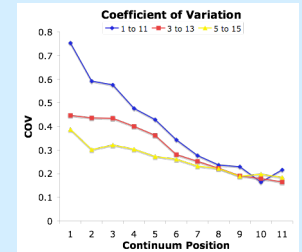


Figure 7: Coefficient of variation. Bars reflect standard errors.

CONCLUSIONS

Both accuracy and RTs reflect a robust end effect on both ends of the stimulus continuum for each of the 3 stimulus ranges. This indicates that the most difficult numerosities are those in the middle of a continuum. Thus, rhesus macaques appear to use an estimation mechanism for that is influenced heavily by relative continuum position. Weber's Law does not predict these results.

Continuum position is not the only factor affecting accuracy and RTs. Accuracy and RT data are significantly different between the 3 stimulus ranges. Although the functions for each range are similar, they are displaced along the y-axis, suggesting that the absolute magnitude of the values in the stimulus range is also an important factor. In addition, data shows a distance effect, as accuracy increases with the numerical distance between the target and the nearest distractor.

Median RTs to the sample also differ significantly between each of the 3 continua, although in the reverse direction of test RTs. While the values of each range are different, this is not an effect of the absolute magnitude of the stimuli because within a continuum, magnitude has no significant effect on RT to sample.

While accuracy shows a distance effect and an effect of the overall magnitude of the stimulus range, results do not conform to Weber's Law. Weber's Law entails scalar variability, in which the variability of responses increases with stimulus magnitude. In each of the 3 stimulus ranges, the standard deviation for responses does not increase with target magnitude and the coefficient of variation is not constant. Instead, the coefficient of variation decreases with increasing magnitude for all stimulus ranges, again suggesting the importance of relative continuum position for estimation.

ACKNOWLEDGEMENTS

Terrace Lab: Dustin Merritt, Ph. D., Nate Kornell, Ph. D., Patricia Anstatt, Tamar Kornblum, Patrick Kennedy, Niko Reyes, James Lavery, Devika Bhushan

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