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The Neural Basis of Parallel Individuation and Numerical Estimation

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Introduction

Research on numerical cognition using behavioral, neuroimaging, developmental and cross-cultural methods, converges on the conclusion that there are two distinct systems for the perception of numerical quantity:

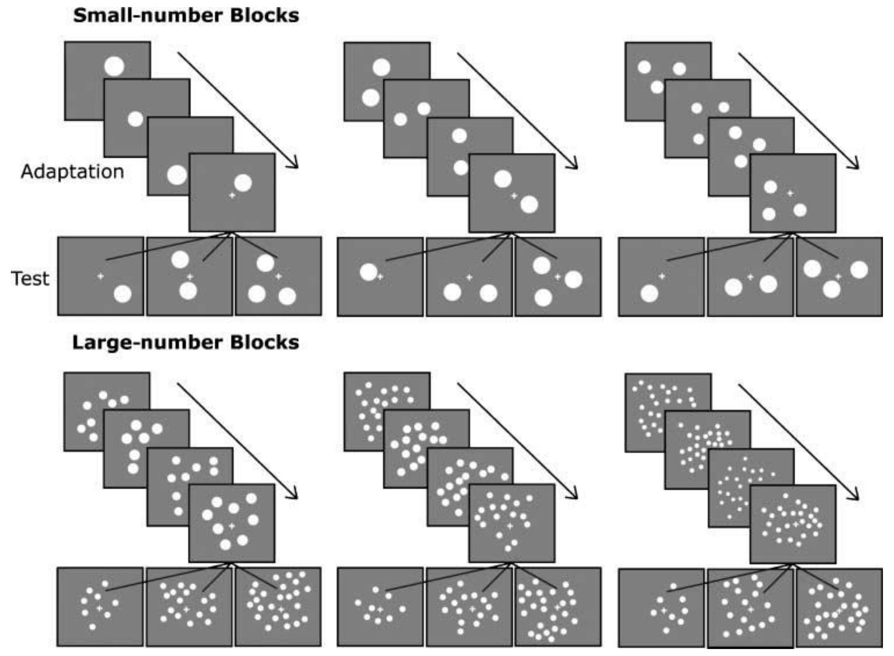
1. A small-number system (1~3) invoking parallel individuation, object files, and "subitizing"
2. A large-number system (4+) that is based on Weberian analog magnitude estimation

Previous EEG research in numerical cognition:

•Previous studies have found ERP N1 negativities associated with perception of numerical values in the posterior parietal-Occipital-Temporal (POT) region (Temple & Posner, 1998)

•Hyde & Spelke (2009)employed a passive numerical viewing task to examine ERPs associated with ratio changes within the small number (1-2-3) and large number (8-16-24) range. Participants viewed 4 dot displays with the same number of dots (adaptation), followed by a test array with either the same number or a small vs. large ratio change. Changes remained within the small or large number sets. No changes crossed between small and large number values.

Figure 1 Hyde and Spelke design: Only test trials are used for ERP analysis



•H&S examined test items that involved changes (or no change) following the adaptation phase. Within the small number range, the N1 ERP showed scaling of ERP magnitude with numerical quantity (see also Hyde & Wood, 2011). That is, numerical value (1,2,3) correlated with N1 deflection. A later P2p positivity discriminated ratio changes within the large number range: 8 vs 16 vs 24 (but not the smaller range)

Design Themes

FIXING BOREDOM PROBLEMS IN DESIGN:

•Participant boredom was a serious concern when replicating the H&S procedure. Many fell asleep most were bored, inattentive and unhappy

•Instead of passive viewing of thousands of dot patterns, the task was to detect changes in the numerical value, and to press a key when such changes occurred. Number of trials between changes was varied between 3 and 5 so as to be unpredictable

•At the end of the experiment, each participant was given a score of how many correct responses they got, and were given a reward of a lottery scratch off card for every 50 items they got correct. They were also updated on their score during breaks between testing blocks

•We used data from both change trials and no change trials in the ERP analysis

LOOKING FOR CATEGORICAL SMALL-LARGE DIFFERENCES WITHIN A NARROWER RANGE (1 to 6)

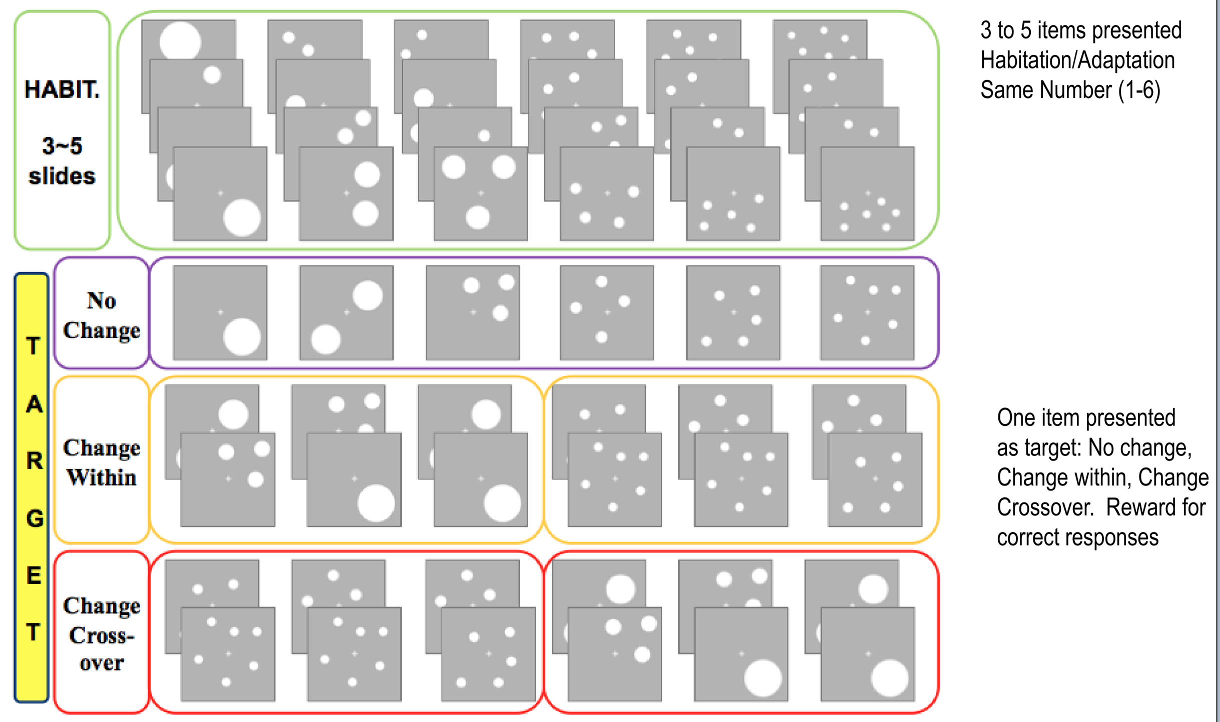
•The H&S experiment examined difference that occurred between small and large set sizes that were perceptually distinct with a large gap between the small and large number ranges, differences in dot sizes etc. (see Figure 1)

•We wanted to examine the small-large distinction within a narrower continuous range of 1 to 6, to see if there was a clear categorical boundary between small and large number response

•We wanted to see if there was a distinct ERP response pattern when changes crossed over between small (1-3) and large(4-6) set sizes as compared to responses to within set changes.

Design and Procedure

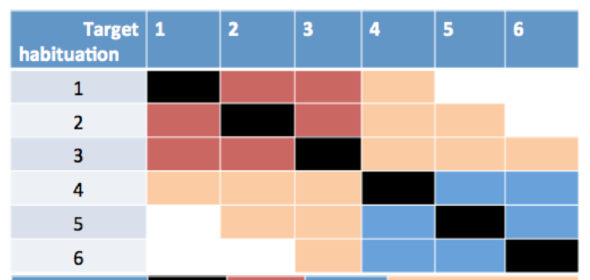
Figure 2 Revised Design of Present Study



Basic Design Elements:

- Same numerical value presented on 3-5 trials.
- Followed by Target:
  - A: Same Number
  - B: Change within small or large sets (e.g., 3-2, 1-3, 6-5)
  - C: Cross-over between S/L (e.g., 2-4, 1-5, 6-2)

- Analyses will examine ERPs associated with Habituation/Adaptation trials to different numerical values
- RTs and ERPs examined to change detection trials comparing: Within Small, Within Large, Crossover Small to Large; Crossover Large to Small. Responses within these were averaged within participants.



	No change	Within Small	Within Large	Cross over S→L	Cross over L→S
Pairs of quantities (e.g., "11": 1→1, "12": 1→2...)	11, 22 33, 44 55, 66	12, 13, 21, 23, 31, 32	45, 46, 54, 56, 64, 65	14, 24, 25, 34, 35, 36,	41, 42, 43, 52, 53, 63

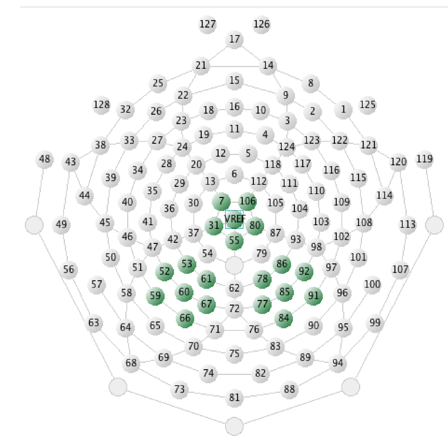
EEG Data Acquisition and Processing

- Apparatus
  - 128-channel EGI Geodesic Sensor Net with High Impedence Amplifier
- EEG Recording
  - Recorded in a shielded sound attenuating chamber
  - Amplified analog voltages were stored digitally
  - The signals were recorded a 0.1- 100 Hz bandpass filtered
  - Sampled and digitized at 250 Hz using Net-Station EEG acquisition software and EGI amplifier
  - Impedance of electrodes was kept below 50 kΩ
  - Individual voltages were referenced to the average across all electrodes

- EEG Data Processing
  - 40 Hz low-pass digital filter applied
  - Segmentation of 800ms length epochs, starting 100 ms before onset of stimuli
  - Artifact rejection
  - Epochs associated with the same category **(i.e., no change, within small, within large, or cross over)** were averaged within subjects
  - EEG recordings were re-referenced to average and the baseline correction was performed to 100ms interval preceding the stimulus on-set.

Montage and ERP Timing ROI

- EEG Data Analysis
  - Montages for the ERP components
    - Cz and neighboring electrodes
    - Left and right occipital-temporal-parietal junction
  - Time windows and ERP components:
    - Time Slice 1 (N170): 160~180 ms
    - Time Slice 2 (P3): 416~476 ms

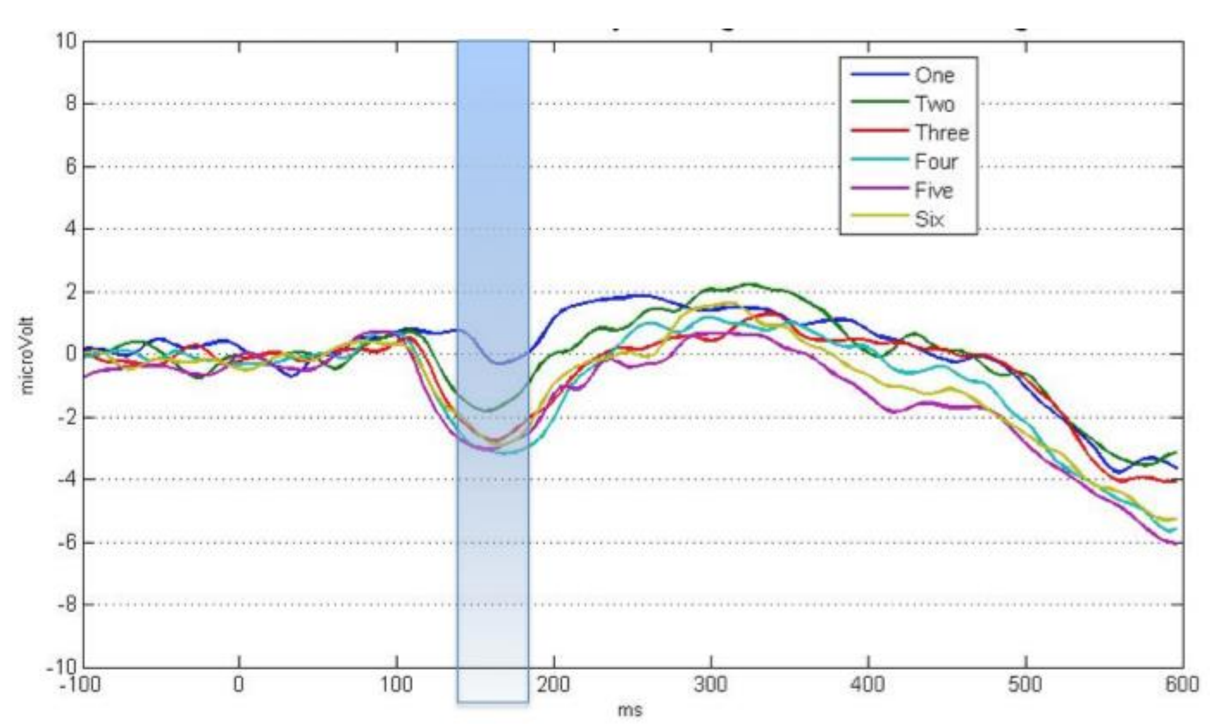


Participants

- 15 adults (4 male, 11 female)
- Ages ranged from 23 to 43 years (mean = 27.7)
- All subjects were right handed.
- All completed the experiment with no more than 2 errors for any participant over the whole experiment

Results

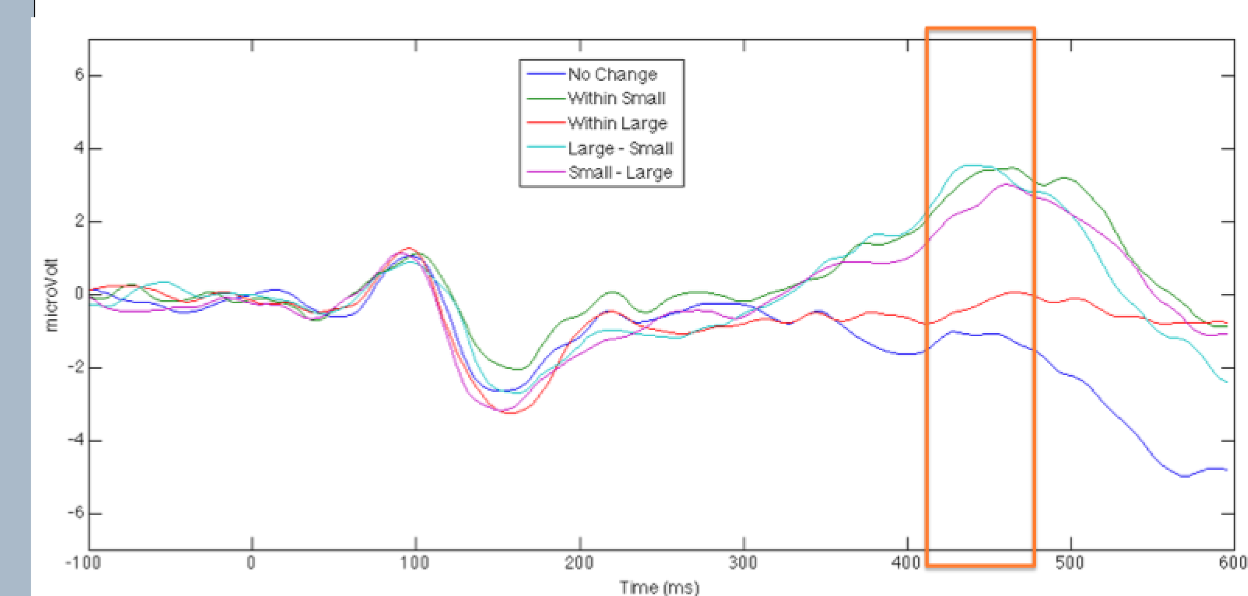
ERPs to individual magnitudes (1~6) in habituation/adaptation trials without change in numerical value

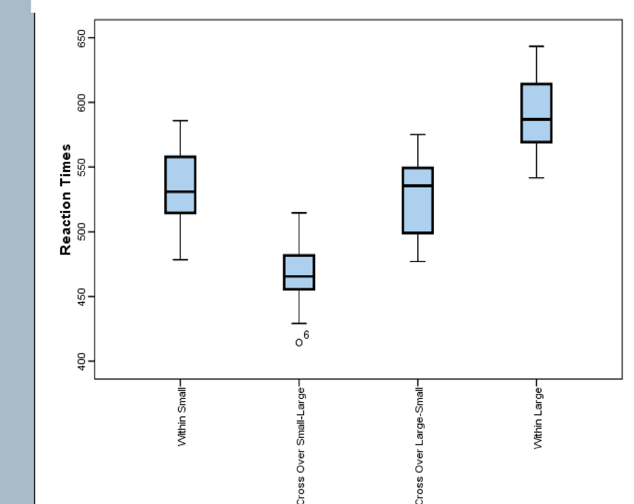


- For the early ERP component (N170; 160~180 ms), there was a separation of ERPs within the subitizing range (1~3) but not beyond (4~6)
- Relative magnitudes of ERP deflections corresponded to ordered numerical magnitudes within the small-number range, but not within the large number range
- This scaling of N1 ERP to numerical magnitude replicates that found in Hyde and Spelke (2009) and Hyde and Wood (2011). Scaling is somewhat clearer in these data, and the categorical break between 1-3 and 4-6 is apparent
- No later deflection is found that distinguishes between small and large numerical values, but these data do not include change trials only same number adaptation trials

Reaction Times and ERPs to change of quantities

- Late Positivity (400-500ms) was observed for all change categories except for "within large"





- RTs were significantly slower to the Within-Large condition compared with each of the other conditions. (p's < 05)
- Significantly slower RTs to this condition are reflected in the lack of deflection in P3 for ERP analysis

Summary and Conclusions

- These data, taken together, suggest a neural basis for the differentiation of small vs. large number perception at early stages of processing, and a later stage that involves more complex numerical processing that is employed in change detection task
- Like Hyde & Spelke (2009), numerical magnitude of dot displays was reflected in commensurate ordered magnitude of ERP deflections
- The present study examined a smaller numerical range (1-6) so that small vs. large contrasts were less perceptually striking
- Distinctions in ERP deflection reflect a clear categorical break between small and large quantities as found in previous behavioral, developmental and cross-cultural and cross-species tasks
- ERPs to change detection at 400-500 ms were found in the faster responding conditions, but not in the slow (within large) condition suggesting greater processing demands for this condition

References

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