The Neural Instantiation of Number

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Introduction

Fundamental to calculation and arithmetic competency is the ability to abstractly represent numerical quantity. While much is known about the psychophysics of human quantity representation, little is known about the neural instantiation of this key ability. Through ERP (event-related potentials), we characterize the nature of multidigit numerical representations. Dehaene (1996) revealed that bilateral regions of parietal cortex are involved in judging the largest of single digit numbers (1,4,6, and 9) from the number 5. Our research replicates his findings and also considers the nature of the neural representation of the magnitudes themselves. Preliminary studies have revealed systematic variations in ERP signature in response to the presentation of small numerical quantities (range: 1 – 16). This activation is localized to bilateral inferior parietal regions and occurs 220 ms after stimulus onset (Whalen, West, & Cook, 2002). The present work investigates the neural representation of larger quantities, and the mapping of multidigit numerals to neural quantity representations.

Methodology

Participants were shown Arabic digits ranging from 0 to 99. Stimuli were randomized and presented individually for 500 ms. Because Arabic numerals are known to automatically elicit representations of numerical magnitude (Lefevre et al., 1988; Naccache & Dehaene, 2001), no response was required of participants. Participants were also periodically asked to compare the relative numerical magnitude of two sequentially presented numbers (participants judged whether the second number in the pair was “smaller” or “larger” than the first). Event related potentials were recorded using a 128 channel EGI (Electrical Geodesics, Inc.) Sensor Net. ERPs were collected for each tens quantity (e.g, 3 of 34), units quantity (e.g, 4 of 34), and overall magnitude (e.g., 34) for 250 ms prior to stimulus onset to 500 ms post onset.

Results

Using single and double-digit Arabic numerals ranging from 0 to 99, we discovered functionally distinct neural representations for the individual numerals that compose a multidigit number (e.g., the "3" and "4" of the multidigit numeral "34") and for overall numerical magnitude. Regression analysis over 20 ms intervals at each electrode site revealed systematic linear variation in neural voltages relative to the numeral presented. This included distinct representations for both the tens and units quantities, and the overall magnitude. Overall magnitude was represented bilaterally in inferior parietal regions, while tens and units representations were localized to the right superior parietal gyrus. While the ERP signature for each quantity was localized to unique regions of parietal cortex, the onset of the representations were nearly simultaneous, commencing approximately 220 ms after presentation of the numeral. The linear changes in ERP signatures relative to the magnitude presented suggests that number is represented linearly in parietal cortex, a finding consistent with studies of quantity representations in non-humans (Gallistel & Gelman, 2000).

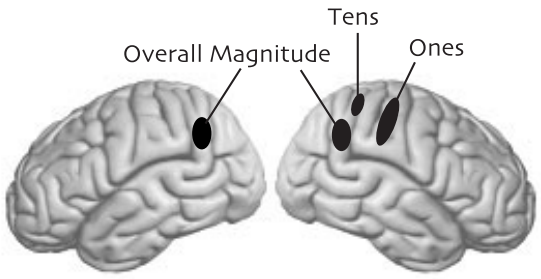

Figure 1: Source Localization for Tens, Units and Overall Magnitudes.

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