

Abstract representations of numbers in the animal and human brain

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1 Criteria for an abstract representation of numbers

Arguments for a network/module/faculty

- spontaneous emergence at a young age in all healthy members of a species
- presence across species (ie, humans and animals)
- lesion & brain-imaging studies indicate a specific neural substrate

2 Number processing in infants

Sample Experiment - Comparing number/quantity

Infants were habituated to a slide with a fixed number of dots (eg, two) At habituation, the presentation of slides with a different number of dots yielded significantly longer looking times, indicating dishabituation and therefore discrimination between two and three.

Sample Experiment - Adding/Subtracting

Show a toy hidden behind the screen, add one or take one away. Change the identity of the objects (so that its not their identity that matters) and remove screen. Children look significantly longer at incorrect additions and subtractions.

3 Number processing in animals

The above experiments were also performed on animals with similar results. In addition, cross-modality experiments were performed on animals with similar results. This indicates abstraction from visual or auditory representations to abstract representations of number.

Sample Cross-modality Experiment - Comparing number/quantity

Rats trained initially on distinct auditory and visual discrimination tasks were shown later to generalize to novel sequences in which auditory and visual stimuli were mixed.

Manipulation of symbolic representations of number

Monkeys and chimpanzees have been taught to recognize the Arabic digits 1 - 9 and to use them appropriately to refer to sets of objects.

-Caveat: “such experiments cannot be taken to indicate that exact symbolic or linguistic number processing is within the normal behavioral repertoire of animals. However, they do indicate that abstract, presumably non-symbolic representations of number are available to animals and can, under exceptional circumstances, be mapped on to arbitrary behaviors that can then serve as numerical symbols ”

4 Parallels between animal and human representations of number

Humans and animals show two effects:

Numerical distance effect

The ability to discriminate between two numbers improves as the numerical distance between them increases.

The number size effect

For equal numerical distance, discrimination of two numbers worsens as their numerical size increases.

-Caveat: “Comparison times and error rates are a continuous, convex upward function of distance, similar to psychophysical comparison curves.”

→ Question for Discussion: because animals and humans share these effects, and these effects are also seen in other comparisons, are these effects due to number, comparing, or are the effects seen in other comparisons derived from using the number “network”?

5 Deficits of semantic number processing in brain-lesioned patients

Lesions in Areas of the Brain¹

- inferior intra-parietal area of left hemisphere lesions
 - might result difficulties in comprehending, producing and calculating with numbers
- inferior intra-parietal area of right hemisphere lesions
- parietal acalculia lesions
 - might result in “disorganization of an abstract semantic representation of numerical quantities rather than of calculation processes per se”
- dominant-hemisphere inferior parietal lesions and Gerstmanns syndrome.
 - might be specific impairments in subtraction and number bisection, suggesting disturbance to the central representation of quantities.

6 Brain-imaging studies of number processing

Processing in Areas of the Brain²

- left parietal area
 - multiplication yielded greater activity
- left inferior parietal area
- right parietal area
- right inferior parietal area
 - Relative to letter reading, digit comparison yielded greater activity

7 “Take home message”

We have good understanding of 2 sorts of number/quantity related effects exhibited by animals, infants and adult humans. We have some evidence for where number/quantity processes take place in the brain (parietal area). Further research/models are needed to relate these effects to processes in the brain. Language impairment can confound the investigation number/quantity impairment.

¹Needs fleshing out

²Needs fleshing out

8 Some missing links and pointers to further research

Lacking

- directly parallel studies in animals and humans
- studies of higher numbers than 6 in infants
- involvement of the intraparietal cortex in infants and animals remains speculative. Non-invasive brain-imaging techniques applicable to infants have not been applied to number processing.
- lesion and electrophysiological studies of number in animals.