Introduction

Visual performance improves substantially after birth in primates. Previous studies in V1 have found that neural sensitivity is relatively mature at birth and changes little after birth. We used a novel approach to assess behavioral maturation, and compared the results to physiological data from extrastriate cortex. Recent work has demonstrated that the presence of “naturalistic” image content in a visual stimulus preferentially drives neurons in areas V2 and V4. We developed a behavioral paradigm to measure sensitivity to naturalistic image content and used multi-electrode arrays to record neural responses to the same stimuli in areas V1, V2, and V4.

Methods

Behavior: We trained 8 Macaca nemestrina monkeys (3 females) to perform a 4-alternative forced choice task. After fixation on a central square, 4 textures appeared, one of which was naturalistic and varied in naturalness; the others were different noise examples from the same texture family. The monkeys learned to fixate the naturalistic texture for 400 ms to earn a juice reward. Several animals were tested at multiple ages; the earliest measurement was at 14 weeks of age.

Neurophysiology: We implanted two female monkeys with two 96-channel “Utah” arrays. The arrays were placed on the V1/V2 border (specific site locations were determined based on gross anatomical and physiological evidence) and in area V4, all within 1.5 degrees of the center of gaze. We recorded neural responses to texture images flashed serially, for 200 ms at 200 ms intervals.

Results - behavioral sensitivities increase with age

Behavioral sensitivities increase during early life -
- Psychometric functions for one animal at two ages (above, left). 
- Naturalness sensitivity across texture families versus age, as measured in our 4AFC task (above, right).
- Colors represent different monkeys; some monkeys performed both tasks.

Results - temporal dynamics

Decoding performance improves hierarchically -
- Normalized firing rate to naturalistic and noise textures (bright and desaturated colors) for data from a single animal in V1, V2, and V4 (left), averaged across multiple texture families.
- We projected noise and naturalistic examples from our test set onto learned regression weights, to measure sensitivity over time (right).
- The discriminability between naturalistic and noise textures, measured as a discriminability (d’), median absolute deviation, (MAD), is shown for each 10 ms bin (each bin was trained and tested separately) using the same data shown on the left. We used populations of 20 sites.
- Points above the curves show latencies at which d’ first reaches half its maximum, points to the right show peak performance. For panels with two curves, each curve is from a different monkey.

Results - comparing perception and physiology

Extracting neurometric functions -
- We computed neurometric performance to match our psychophysical task.
- Performance for a single V4 session at 6 mo (left), across multiple coherences (inset, above).
- To measure population performance, we integrated from 50-200 ms after stimulus onset (gray lines).
- We generated a population neurometric function for each session. Shown are neurometric functions from V2 and V4, from one animal, at two ages (right).

Neural sensitivities remain stable from 6 to 12 mo -
- Neural sensitivity remains stable between 6 and 12 months in V1, V2, and V4 (left). Symbols represent different monkeys.

Conclusions

- Neural naturalness representation is stable between 6 and 12 months.
- The duration of the population response shortens with age.
- Behavioral naturalness sensitivity increases by ~1.6x between 4 and 20 months of age.
- Neural sensitivity may arise in a primarily feed-forward manner.

References


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