EXTENSIVE CHILDHOOD EXPERIENCE WITH POKÉMON SUGGESTS ECCENTRICITY DRIVES ORGANIZATION OF VISUAL CORTEX

Jordan Clemsen

EARLY BRAIN DEVELOPMENT

- Cell Differentiation
- Brain growth until 14 for boys
- Selective pruning after adolescence
- Development differs among individuals
- VTC = childhood experience
- MFS lateral vs medial and what type of stimuli?

ECCENTRICITY BIAS

- Location and Size
- Central or Peripheral
- One-eyed kittens
- Learning to read
- Face recognition

POKEMANIA

- 1996
- Handheld playing device with limited screen size
- Pokemon were 2.5 x 2.5 cm region and rewarded upon categorization
- Not physical or animate
- Not location or face based stimuli

METHODS

- 11 early adult
- 3 females, tested by naming 40 Pokemon
- Began playing 5 to 8 years
- fmri while viewing; animals, Pokemon, human faces, cartoons, words, cars, bodies, corridors and cars.
- MVPA of VTC responses

METHODS II

- Stimuli was presented at 2 Hrtz
- Oddball concentration task
- Stimuli different from sight
- 6 times
- Controls

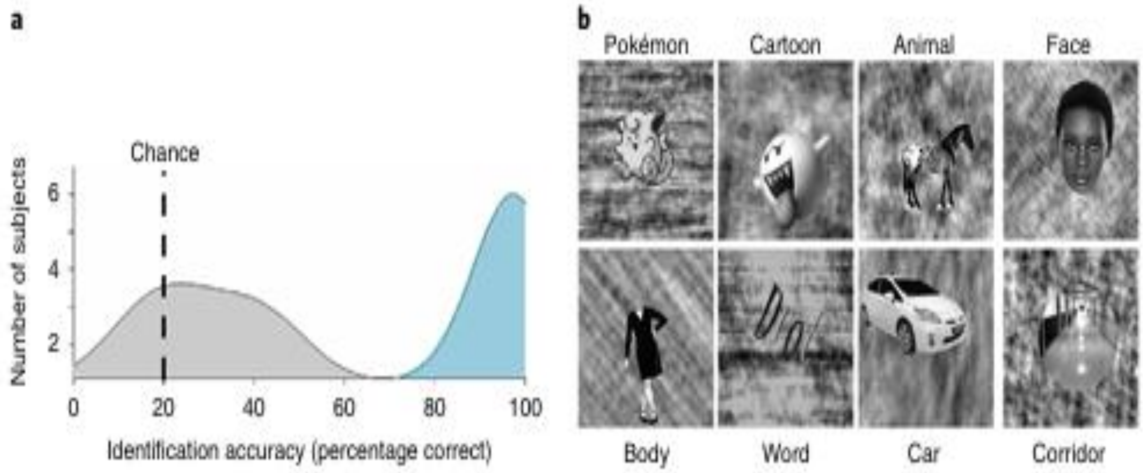

Fig. 1 | Localizer stimuli and behavioural naming performance. a, Distributions of participant accuracies from a five-alternative-choice Pokémon naming task outside the scanner. Experienced participants (blue; $n = 11$) significantly outperformed novices (grey; $n = 9$). **b**, Example stimuli from each of the categories used in the fMRI experiment. In each 4 s trial, participants viewed 8 different stimuli from each category at a rate of 2 Hz while performing an oddball task to detect a phase-scrambled stimulus with no intact object overlaid. Participants completed 6 runs, of 3 min 38 s each, using different stimuli. See https://www.pokemon.com/us/pokedex/ for more general examples of Pokémon and Supplementary Fig. 9 for more examples of the pixelated GameBoy Pokémon stimuli.

FMRI RESULTS

- Averaged RSM across groups
- Pokemon Positive correlation with animals
- Pokemon Positive cohort ($r = 0.27 \pm 0.11$; significant between group difference: $t(20) = 4$, $P < 0.001$, $d = 1.8$).
- Pokemon Positive cohort significantly dis similar (all $t(20) < 4.2$, all $P < 0.001$, all $d > 0.89$) from those of faces ($D \pm$ s.d. $= 0.97 \pm 0.08$), bodies (1.1 ± 0.08) and animals (0.9 ± 0.07)
- Pokemon Negative group was not statistically dissimilar. ($t(20) = 0.52$, $P = 0.6$, $d = 0.1$
- VTC experience variability tested by independent classifier
- Differential attention to Pokémon across groups is not the driving factor leading to the distinct and reproducible representation of Pokémon stimuli in the VTC of experienced participants

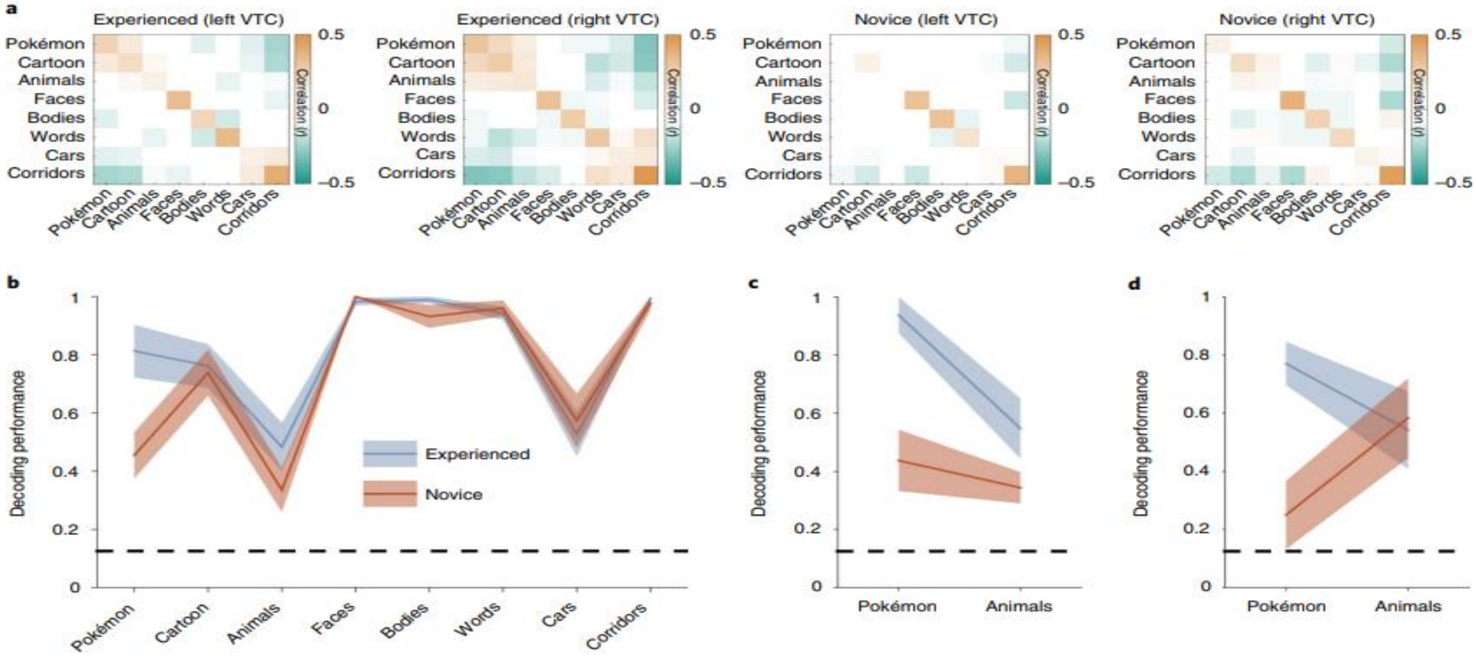

Fig. 2 | Experienced participants demonstrate a consistent and distinct representation for Pokémon compared to novices. a, RSMs calculated by correlating distributed responses (z-scored voxel betas) from an anatomical VTC ROI across split halves of the fMRI experiment. Positive values are presented in orange, negative values in green and near-zero values in white (see the colour scale, which applies to all four RSMs). **b**, The decoding performance from the winner-takes-all classifier trained and tested on split halves of the fMRI data from the bilateral VTC. The shaded region shows s.e.m. across participants within a group (experienced participants, $n=11$; novices, $n=11$). The dashed line indicates the chance level performance; decoding performance is represented as a fraction of 1, with 1 corresponding to 100% decoding accuracy. **c**,**d**, The decoding performance from distributed bilateral VTC responses for experienced ($n=4$) and novice ($n=5$) participants in the original oddball task (**c**) and when brought back to undergo an additional fMRI experiment with an attention-demanding two-back task (**d**). The same participants are shown in **c** and **d**.

STATISTICAL PARAMETRIC MAPS

- But does Pokemon generate a ubiquitous response pattern across positive subjects? (No!)
- Statistical parametric maps implemented to contrast the response to each category versus all others (units: T values) and compared across groups.
- eccentricity, animacy, size and curvilinearity
- Physical, lateral and medial axis
- Preference for faces was found in the lateral FG and preference for places in the collateral sulcus in Pokemon Positive
- Pokémon stimuli present in the lateral FG and occipito-temporal sulcus… For every Pokemon Positive participant!

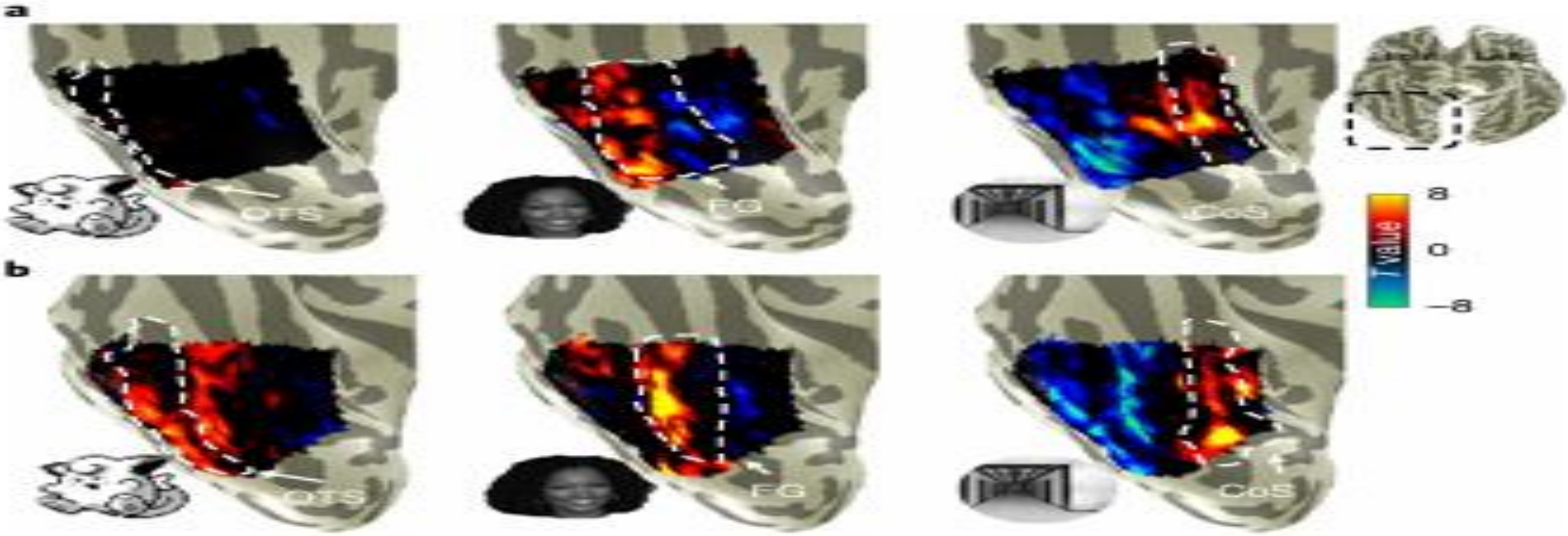

Fig. 3 | Distinct cortical representation for Pokémon in experienced participants. a,**b**, Unthresholded parameter maps displayed on the inflated ventral cortical surface zoomed on VTC (see inset for the location on a whole-brain map) in an example novice participant (26-year-old female; **a**) and an example experienced participant (26-year-old male; **b**) for the contrasts of Pokémon, faces and corridors, each versus all other stimuli. Dashed lines delineate cortical folds; OTS, occipitotemporal sulcus; FG, fusiform gyrus; CoS, collateral sulcus.

WHY POKEMON?!

- When examined for fovel Bias (Rectilinearity Toolbox),
- Foviate Pokemon vs faces ($t(286) = 15.7$, $P < 0.001$, $d = 1.85$
- Both Pokémon and faces generate significantly smaller retinal images than corridors ($ts > 20$, $Ps < 0.001$, $ds > 2.5$), which often occupy the entire visual field and thus generate large retinal images that extend to the peripheral visual field even when foveated on.
- Pokémon are still perceived to be significantly more linear than faces ($t(49) = 6.9$, $P < 0.001$, $d = 1.44$).

METHODS FOR WHY POKEMON!?

- 28 Independent raters -> real world size, /= retinal size
- 1-7
- average game size: 1.2 ± 0.95 m; average rater size: 0.82 ± 0.28 m
- Raters perceive Pokémon to be larger than faces ($t(176) = 26.3$, $P < 0.001$, $d = 5.4$) but smaller than corridors ($t(176) = 16.9$, $P < 0.001$, $d = 3.48$)

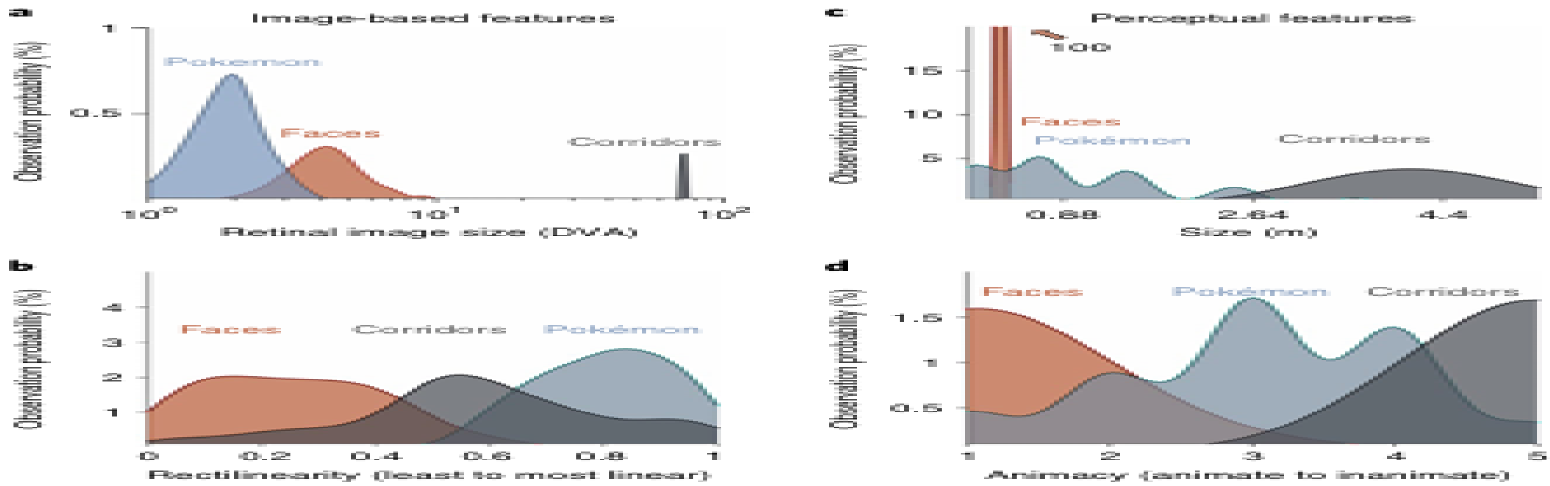

Fig. 4 | Different visual feature statistics predict different cortical locations for Pokémon. a, Distributions of retinal image sizes produced by Pokémon (blue), faces (orange) and corridors (grey) in a simulation that varied viewing distance across a range of sample stimuli. DVA, degrees of visual angle. *X* axis shows log-scale DVA. **b**, Distributions of the relative rectilinearity scores of faces, corridors and Pokémon, as measured using the Rectilinearity Toolbox[25] (0, least linear; 1, most linear). **c**, Distributions of the perceived physical size of Pokémon (from 28 raters) and of the physical sizes of faces and corridor stimuli. The distributions of face and corridor size were produced using Gaussian distributions with standard deviations derived from either anatomical or physical variability within the stimulus category (see Methods). The face distribution extends to a value near 100% (the natural variation of face size is very narrow compared to other stimuli). **d**, Distributions of the scores of perceived animacy collected from a group of 42 independent raters who rated the stimuli of faces, Pokémon and corridors for how 'living or animate' these stimuli were perceived to be (1, animate; 5, inanimate).

METHODS FOR WHY POKEMON!?

- 42 independent raters -> perceived animate
- 0-5
- ($t(82) = 13.2$, $P < 0.001$, $d = 2.88$), but more animate than corridors ($t(82) = 14.5$, $P < 0.001$, $d = 3.18$).
- Animate stimuli are localized to the lateral VTC and inanimate stimuli to the medial VTC

CBA

- Pokemon positive data to Freesurfer cortical space
- 4 main differences;
- Preference for Pokémon reliably localized in the OTS
- Pokemon Positive, Pokémon-preferring voxels (3>T) partially overlapped face-selective voxels on the lateral FG and extended laterally to the OTS, but never extended medially to the CoS, where place-selective activations occur
- Pokémon versus all other stimuli, Pokémon-selective voxels were observed in the lateral FG and OTS of all 11 individual Pokemon Positive
- An ANOVA run with the factors group and hemisphere on the volume of Pokémon selectivity in the VTC revealed a main effect of group ($F(1,1) = 32.75$, $P < 0.001$, $\eta2 = 0.45$), but no effects of hemisphere, nor any interaction ($Fs(1,1) < 0.67$, $Ps > 0.41$, $\eta2s < 0.016$). The median volume in Pokemon Positive was sixfold larger than novices

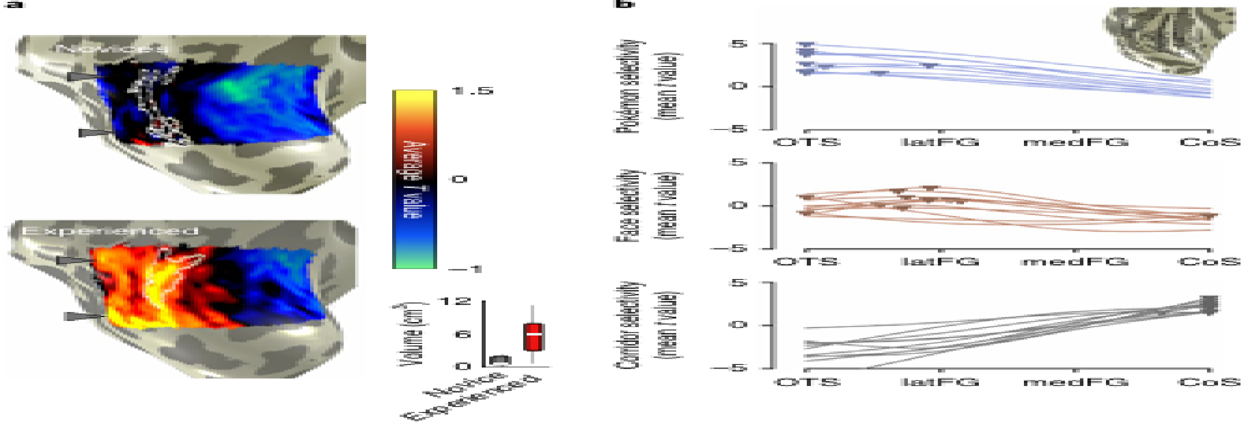

Fig. 5 | Average contrast maps for Pokémon; and anatomical localization reveals lateral VTC responses in experienced subjects. a, Average contrast maps for Pokémon in novice and experienced participants. For each participant, *T*-value maps were produced for the contrast of Pokémon versus all other stimuli. These maps were aligned to the FreeSurfer average brain using cortex-based alignment (CBA). On this common brain surface we generated a group-average contrast map by averaging maps across all novice participants and all experienced participants. Group-average maps are shown on an inflated right hemisphere of one of our participants, zoomed in on the VTC. White outlines show group-average face-preferring voxels (average $T > 1$) from each respective group. Grey arrows show two peaks in the Pokémon-selectivity maps of experienced participants; the same arrows are shown next to the novice map for comparison. Inset: box plots show the mean (white line), 25% and 75% quartiles (boxes) and range (black dotted line) of the selectivity volume in novices and experienced participants. **b**, Curves fitted to the mean selectivity for Pokémon, faces or corridors, averaged in one of four anatomically defined regions extending from the lateral to medial VTC (illustrated in the inset for an example participant). Each line represents a participant and the triangles show the peak selectivity values. The peaks for the Pokémon-selectivity curves are significantly more lateral than the peaks for face selectivity. The most lateral ROI is the OTS extending from the inferior temporal gyrus (ITG) to the medial aspect of the OTS. The lateral FG (latFG) ROI includes the lateral FG and ends medially at the MFS; the medial FG (medFG) bin extends from the MFS to the lateral edge of the CoS; the CoS bin includes the CoS up to the lateral edge of the parahippocampal gyrus.

ARE THE EMERGENT RESPONSES TO POKÉMON IN EXPERIENCED PARTICIPANTS SPECIFIC TO THE POKÉMON CHARACTERS THAT PARTICIPANTS HAVE LEARNED TO INDIVIDUATE, OR WILL SIMILAR PATTERNS EMERGE FOR ANY POKÉMON-RELATED STIMULUS FROM THE GAME?

- 5 of the initial Pokemon Positive cohort
- Images of places from Pokemon down sampled faces to block
- Results were unremarkable

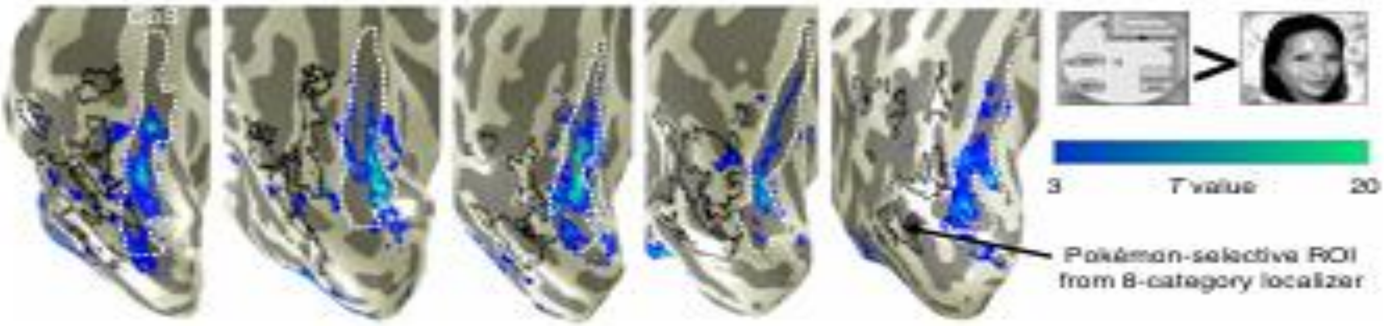

Fig. 7 | Places from the Pokémon game elicit typical place-selective activations in experienced participants. The maps show higher responses to Pokémon scenes than pixelated faces in 5 experienced participants from a follow-up fMRI experiment in which participants viewed downsampled face stimuli (resembling 8 bit game imagery) and scenes from the Pokémon games. The colour bar indicates the T value at each voxel from the threshold ($T > 3$) over the range denoted in the colour scale. Pokémon-selective voxels (outlined in black) do not preferentially respond to Pokémon scenes versus faces; instead, voxels preferring Pokémon scenes versus faces are in the typical location for place selectivity[18], namely, the CoS (outlined in white).

HOW DOES VISUAL EXPERIENCE CHANGE THE RESPONSIVENESS OF THE OTS TO VISUAL STIMULI?

- Both cohorts quantified (Freesurfer)
- Pokemon ROI created by cortical average using CBA to project to controls brain
- Pokemon + Normal
- Pokemon > Pokémon than other categories (with lower responses to cartoons and animals and even lower responses to faces, bodies and other stimuli.
- In Pokemon Negative area of Pokemon Positive ROI cohort show the highest amplitude of response to animals, then to cartoons and words and lower responses to the other stimuli.
- Pokémon selectivity is observed overlapping and lateral to the face-selective cortex, hence its own region.

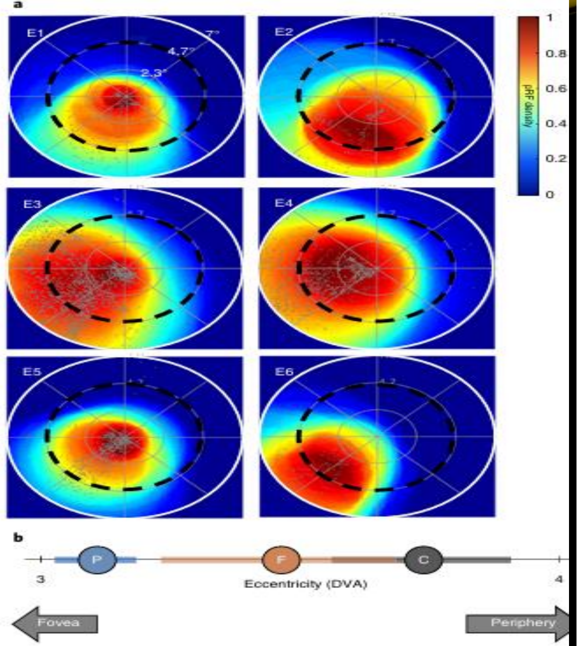

Fig. 6 | pRF modelling reveals that the Pokémon-selective cortex is foveally biased. **a**, Density plots (see colour scale) representing the visual field coverage by pRFs of Pokémon-selective voxels from the right hemisphere in 6 experienced participants. Each plot shows data from a single participant (E1–E6). Density is normalized to the maximum in each participant. Grey dots show pRF centres and black dashed circles represent 4.7° of eccentricity. Only voxels that had more than 10% varian explained by the pRF model were included. **b**, The mean (circles) and s.e.r (coloured bars) of pRF eccentricity averaged within the Pokémon- (blue), face- (brown) and corridor-selective (grey) cortex across participants. Positions towards the left of the line are closer to the centre of the visual field (fovea), measured in DVA.

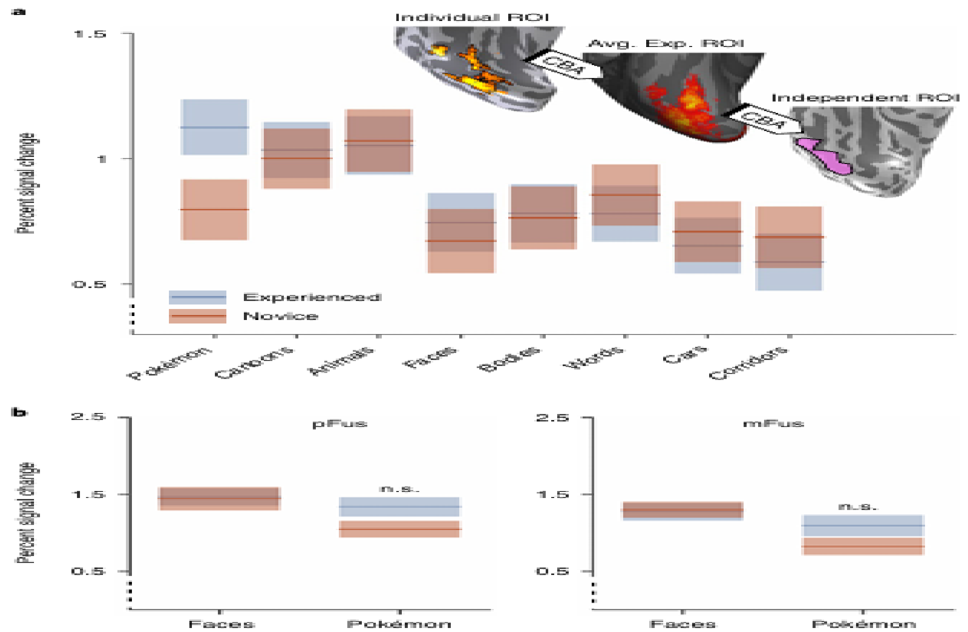

Fig. 8 | Response properties of the VTC vary with childhood experience with Pokémon. **a**, fMRI responses (percent signal change) measured from an independent definition of Pokémon-selective cortex in both experienced and novice participants. ROI, region of interest. **b**, Responses from bilateral pFus- and mFus-faces to faces and Pokémon in experienced and novice participants. Face-selective voxels were defined using odd runs of the fMRI experiment, and percent signal change was calculated from the even runs. Experienced and novice participant responses to both faces and Pokémon in pFus-faces are not significantly different. Responses to faces and Pokémon between groups in mFus are also non-significant. The black dotted *y* axis denotes that the axis does not begin at zero. Shaded regions are s.e.m. Avg. exp. ROI, average experienced ROI; n.s., non-significant.