Supplementary Materials

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Effects of distance between fixations

The main goal of this experiment was to assess both the retinotopic and non-retinotopic factors that affect the multi-voxel pattern of responses throughout the visual system. For that purpose comparisons between spatial patterns of response were divided into four groups: comparisons between conditions in which stimuli appeared in the same retinotopic and the same spatiotopic (screen) position (RS), conditions in which stimuli appeared in the same retinotopic location (R), conditions where stimuli appeared in the same spatiotopic location (S), and conditions where stimuli appeared in different retinotopic and spatiotopic locations (D). Importantly, some comparisons within group D share the same gaze position, while other comparisons are between different fixation positions, which vary in their gaze difference (see Supplementary Figure S1). That is, even though all comparisons in this group are equal in the sense that both the retinotopic and spatiotopic locations of the stimuli in the conditions are different, the distance between their respective gaze positions vary. The same holds for comparisons between conditions of the same retinotopic location (R). On the other hand, comparisons between conditions with the same spatiotopic location (S) are always made between conditions with neighboring fixation points. It is therefore obviously important to disentangle the effect of gaze position, from that of spatiotopic vs. retinotopic effects on the pattern of
activation in the various regions of interest. To address this issue, the distance between the fixation points in each comparison type was indexed. This distance had a value of 0° for comparisons between conditions with the same fixation point, 6.3° for comparisons between conditions with neighboring fixation points, and 12.6° for comparisons between conditions with fixation points further apart (see Supplementary Figure S1).

Figure S1. Distance between fixation points. The compared conditions can be divided according to the distance between the gaze directions in the two conditions to be correlated. These are split to two main categories: on the left, the three distance levels in the retinotopic-identical conditions (R+RS). On the right, three distance levels in the retinotopic and real-world different conditions (D). Since stimuli always appeared next to the fixation point, conditions of the same real world position (S) had only one distance level of 5.7° (neighboring fixation points).

A two-way repeated measures ANOVA was performed on the correlations values (Retinotopic-identical, yes/no; Distance, 0°/6.3°/12.6°) in each of the ROIs along the dorsal and ventral streams. Because conditions with the same retinotopic location were positively correlated while conditions with different retinotopic and spatiotopic locations had negative correlations (see figures 4a-f; 6c & 6d) it is not surprising that the first factor (retinotopic matching) proved to be highly significant [Left MOG/pITS, F(1,14) = 43.87, p<0.001; Right MOG/pITS, F(1,14) = 56.61, p<0.001; Left pIPS, F(1,12) = 36.41, p<0.001; Right pIPS, F(1,12) = 81.94, p<0.001; Left mIPS, F(1,14) = 14.79, p=0.002; Right mIPS, F(1,11) = 34.66, p<0.001; Left aIPS, F(1,12) = 10.00, p=0.008; Right aIPS, F(1,11) = 14.10, p=0.003]. Interestingly, the distance factor proved to be significant as well in 3 of the 8 ROIs [Left MOG/pITS, F(2,13) = 6.48, p=0.011; left mIPS F(2,13) = 10.94, p=0.002; right aIPS, F(2,10) = 6.33, p=0.017] and marginal in two areas [Right MOG/pITS, F(2,13) = 3.79, p=0.051; right pIPS, F(2,11) = 3.86, p=0.054]. The left pIPS and the right mIPS and the left aIPS showed no significant effect of distance between fixation
points (p>0.05). Importantly, no area showed interaction effect between distance and retinotopic identity. That is, about half of the ROIs correlations seem to depend on the distance between the fixation points of the conditions, regardless if the stimuli are in the same retinotopic location or not. Figures 2-s5 depicts the gaze effect in the IPS and LOC.

Figure S2. Similarity index is presented as a function of distance between fixation points in the left and right aIPS. A, Left aIPS, R & RS comparisons. B, Left aIPS, D comparisons. C, Right aIPS, R & RS comparisons. D, Right aIPS, D comparisons. The icon at the central column shows a horizontal slice of the brain of one representative subject (S4) with an overlaid activity map. In all cases, error bars denote SEM. Arrows denote activation in the specific region of interest.
Figure S3. Similarity index is presented as a function of distance between fixation points in the left and right mIPS. A, Left mIPS, R & RS comparisons. B, Left mIPS, D comparisons. C, Right mIPS, R & RS comparisons. D, Right mIPS, D comparisons. The icon at the central column shows a horizontal slice of the brain of one representative subject (S5) with an overlaid activity map. In all cases, error bars denote SEM. Arrows denote activation in the specific region of interest.

Figure S4. Similarity index is presented as a function of distance between fixation points in the left and right pIPS. A, Left pIPS, R & RS comparisons. B, Left pIPS, D comparisons. C, Right pIPS, R & RS comparisons. D, Right pIPS, D comparisons. The icon at the central column shows a horizontal slice of the brain of one representative subject (S6) with an overlaid activity map. In all cases, error bars denote SEM. Arrows denote activation in the specific region of interest.
Figure S5. Similarity index is presented as a function of distance between fixation points in the left and right MOG/pITs. A, Left MOG/pITs, R & RS comparisons. B, Left MOG/pITs, D comparisons. C, Right MOG/pITs, R & RS comparisons. D, Right MOG/pITs, D comparisons. The icon at the central column shows a horizontal slice of the brain of one representative subject S1 with an overlaid activity map. In all cases, error bars denote SEM.

A possible reason for such a gaze effect could be an inhomogeneous visual environment. That is, changes in luminance and background features across the visual field can cause trials with closer fixation points to generate more similar patterns of response than trials with more distant fixation points. An alternative explanation would be that this effect is a result of the modulation of the brain activation by the position of the subject’s gaze. One possible mechanism for such a modulation might be found in the form of “gain fields”. Gain field neurons were first defined by Andersen et al. as neurons with retinotopic receptive fields (i.e., respond to stimuli appearing in a specific visual area relative to the retina), whose activity amplitude is modulated by the gaze position (Andersen, Essick, & Siegel, 1985; Andersen, Snyder, Bradley, & Xing, 1997). Such neurons have been found in the monkey’s parietal cortex in large numbers, and can contribute to a formation of a spatiotopic coordinates system on a population level.

To help clarify this issue, we checked for gaze position effects along the calcarine sulcus (V1). The primary visual cortex is highly sensitive to changes in low level features such as local
contrast and responds to stimuli in retinotopic coordinates. If indeed the gaze effect is due to gain-field modulation we would expect it to be significantly lower in the early visual cortex, as neurons in this area are much less modulated by gaze position than in parietal regions. Alternatively, a strong gaze effect in primary visual cortex would strongly suggest that its source is likely to be related to the visual surroundings. We therefore defined two ROIs, corresponding to areas within the calcarine sulcus of each hemisphere. The right calcarine ROI was selected by contrasting clips (both grasping and scrambled) that appeared in the localizer scan on the left field of view against clips (both grasping and scrambled) that appeared on the right field of view. The analogous procedure was taken to define the left calcarine ROI. As in the other ROIs, the initial contrasts were done at q(FDR)<0.05. The threshold was then adjusted to a stricter one to preserve a unified ROI size of 750m³. The same ANOVA was applied on these new regions, and indeed the effect of gaze position was much more prominent [Left hemisphere, F(2,12) = 59.05, p<0.001; Right hemisphere, F(2,13) = 25.54, p<0.001], suggesting that it is due to the similarity in the visual surroundings between conditions that share the same fixation point (see figure s6). Therefore, we conclude that the source of the gaze effect is not genuinely determined by the position of the eyes in their orbit, per se. Rather, it is likely to be caused by the uncontrolled changes in the visual image that are associated with different gaze directions.
Additional frontal activity

In addition to parietal and ventral visual areas, clear foci of activation were found in frontal areas, specifically in the dorsal premotor area (dPM, bilaterally) and the supplementary motor area (SMA). These frontal regions were identified using the same contrast that was used to identify the more posterior regions (grasping clips against their scrambled version). As with the posterior regions, the statistical threshold for the definition of the ROI was adjusted to maintain an approximate volume of \(750\text{mm}^3\), but never exceeded a false discovery rate of \(q(\text{FDR})<0.05\). We performed the same analysis as with the posterior regions, comparing the mean response level (beta) across voxels for each ROI and comparing between the multivoxel pattern-similarity indices of the different conditions (see figure s7 and s8 for results summary). A 2x2 repeated measures ANOVA on the mean activation showed a significant retinotopic effect in the dPM. The left dPM was more significantly active when subjects viewed (and attended) stimuli that were located right of fixation \([F(1,11)=21.68, p=0.001]\), while the right dPM was significantly
more active when subjects viewed stimuli that were located left of fixation [F(1,11) = 9.94, p=0.009]. MVPA analysis was consistent with these findings, showing significantly higher similarity indices between conditions that shared the same retinotopic location than those not sharing the retinotopic location [Left dPM, F(1,11) = 26.63, p<0.001; Right dPM, F(1,11) = 8.12, p=0.016]. Both methods of analysis did not show any spatiotopic effect (p>0.05). For the SMA, the mean beta activity analysis showed no spatiotopic and no retinotopic effects. That is, activation level was the same for all tested conditions (p>0.05). MVPA analysis presented no spatiotopic effect as well (p>0.05), but showed a significant retinotopic effect [F(1,9) = 8.51, p=0.017].

These regions lie in vicinity to regions that have been recently suggested to play a role in the coordination of reaching and grasping (Cavina-Pratesi et al., 2010). Our video clips consisted of hands grasping objects in different postures, including the final approach of the hand to the right position. As such it is likely that both grasping and reaching circuits are utilized during action observation. Our frontal regions are also close (although a little medial and dorsal) to regions previously reported to be connected to parietal regions and participate in the deployment of attention, (Corbetta et al., 1998; Hagler & Sereno, 2006; Szczepanski, Konen, & Kastner, 2010; Thompson & Bichot, 2005), and in spatial memory tasks (Kastner et al., 2007; Szczepanski et al., 2010).
Figure S7. dPM results. A & B, Mean activation level (betas) of each of the six task conditions in the left and right dPM, respectively. The pattern of activity suggests contralateral retinal representation of the stimuli. C & D, Similarity indices of the four different comparison types in the left and right dPM, respectively. In all cases, error bars denote SEM. The icon at the central column shows a horizontal slice of the brain of one representative subject S1 with an overlaid activity map. Arrows denote activation in the specific region of interest.

Figure S8. SMA results. A Mean activation level (betas) of each of the six task conditions in the SMA. The pattern of activity suggests contralateral retinal representation of the stimuli. B Similarity indices of the four different comparison types in the SMA. In all cases, error bars denote SEM. The icon at the central column shows a horizontal slice of the brain of one representative subject S1 with an overlaid activity map. The arrow denotes activation in the specific region of interest.
Figure S9. Spatial patterns of voxel activation in the MOG/pITS region in two representative subjects shown from a lateral posterior viewpoint of a partially inflated brain. A Activation in the right hemisphere of subject S1. Top row, Patterns of activation in conditions 1, 3 & 5 which share the same retinotopic position (left side). Bottom row, patterns of activation in conditions 2, 4 & 6 (retinotopic right). The two middle columns therefore represent conditions that match spatiotopically (left, 2 & 3; right, 4 & 5) but are in symmetrically opposite sides in their retinotopic location. Note the clear reversal of colors between the top to bottom spatial patterns. This clearly demonstrates that as in the lateral occipital cortex, the location of the image in retinotopic coordinates governs the response in the ventral regions, although once again the retinotopic preference is stronger in the more posterior parts. B & C activations in the left and right hemispheres of subject S2, respectively. STS denotes the Superior Temporal Sulcus.
Effects in the early visual cortex

We contrasted scrambled versions of the clips against their normal version (scrambled > clips, opposite of the contrast used to define the main ROIs) to check for effects in the primary visual cortex. This reverse contrast resulted in strong activation near the occipital pole, extending into the calcarine sulcus, consistent with existing literature that recognize these areas as sensitive to local changes in contrast (for review see: Wandell & Winawer, 2011). Figure S10 shows the MVPA results for the left and right primary visual cortices. It can be seen that the retinotopic effect is significantly stronger than in other ROIs: The similarity indices range from ~1.1 for retinotopically matching conditions to ~ -1 for the retinotopically different conditions, while the highest similarity index in the other ROIs was ~0.5 (right MOG/pITS). The size of the retinotopic effect was confirmed statistically by performing the same ANOVA that was performed on all other regions, which yielded a strong retinotopic effect [left V1, F(1,13) = 126.66, p<0.001; right V1, F(1,14) = 101.53, p<0.001]. Strong retinotopic mapping was documented before, and is consistent with the small size of receptive fields of neurons in the early visual areas (Dumoulin & Wandell, 2008).

Figure S10. MVPA results for the early visual areas. Left, Similarity indices of the four different comparison types in the left early visual cortex. Right, Similarity indices of the four different comparison types in the right early visual cortex. In all cases, error bars denote SEM.
### Coordinates of known topographically mapped regions

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**Table S1.** Relation of pIPS, mIPS, aIPS, dPM & SMA to known visual maps. Coordinates are in Talairach space.
Eye Tracking Data

Our task required subjects to maintain fixation while attending to peripheral stimuli. We used an eye tracking device to verify that subjects follow this desired behavior. It was especially important to verify that subjects did not shift their gaze towards the stimuli and away from the fixation point. In addition to carefully inspecting the subjects’ eye movement during the experiment, we analyzed their eye position off-line. We checked if the subjects were able to keep fixation, and not glance at the stimuli. For this purpose we analyzed the number of fixations at the stimuli and the percentage of fixation time directed at the stimuli out of the total data points for each subject for each block. Blocks in which subject had more than 2 fixations on the stimulus were excluded. Similarly, blocks in which the subject fixated more than 10% of the time on the stimulus were excluded. Three subjects who failed to maintain stable fixation in more than 4 blocks (out of a total of 48 blocks) were removed from any further analysis. For the remaining subjects, a total of 6 out of 576 blocks were excluded from the analysis. For the remaining data, 96.47% of the fixations were within 0.9° radius from the fixation points, and thus not directed at the stimuli. Of the remaining 3.53% of the fixations, 63.81% were in the direction of the relevant stimulus location and the rest in the opposite direction. Thus, only 2.25% of all fixations might overlap with the stimuli location. Similarly, 98.45% of the fixation time was directed at the area within 0.9° radius from the fixation points. Of the remaining 1.55% fixations time, 39.18% was associated with gazing at the direction of the relevant stimuli, and the rest with gazing at the opposite direction. Thus, only 0.61% of the total fixation time was at locations that could overlap with stimuli location.

References


