

Dissociable systems for visually guided navigation versus reaching and grasping in human parietal cortex

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Parietal cortex is thought to support visually guided actions, but whether it contains distinct regions specialized for different actions—such as navigation, reaching, and grasping—remains unknown. Prior work implicates the superior parietal lobule (SPL) in navigation and the superior parietal occipital cortex (SPOC) in reaching and grasping, yet whether these are truly dissociable is unclear. We addressed this using fMRI in adults. Participants viewed four stimulus types: Dynamic Scenes (first-person motion through scenes), Static Scenes (static images from these movies), Contextual Reaching and Grasping (first-person reaching and grasping on a scene background), and Isolated Reaching and Grasping (reaching and grasping actions on a black background). A double dissociation emerged: SPL responded significantly more to Dynamic than Static Scenes—consistent with its role in visually-guided navigation—and, critically, more to Dynamic Scenes than either reaching and grasping condition. By contrast, SPOC responded significantly more to both reaching and grasping conditions than to either scene condition. Resting-state functional connectivity further supported this double dissociation: SPL showed stronger connectivity with “leg-motor” than “arm-motor” cortex, whereas SPOC showed the opposite pattern. These findings reveal two distinct parietal systems: SPL for visually-guided navigation and SPOC for visually-guided reaching and grasping—clarifying how the parietal cortex organizes visually guided action.

Keywords connectivity, dorsal stream, fMRI, place processing, visually guided action

Introduction

Recent research has identified a new scene-selective region within the superior parietal lobule (SPL) that i) responds to first-person motion information through scenes, ii) encodes “sense” (left/right) information, iii) is selectively engaged during a virtual navigation task, and iv) exhibits preferential connectivity with the occipital place area (OPA) (Yoon et al. 2025). These findings suggest that SPL plays a specialized role in “visually-guided navigation” (i.e. our ability to move about the immediately visible environment, avoiding boundaries and obstacles). However, SPL lies adjacent to another parietal region, the superior parieto-occipital cortex (SPOC), which has been implicated in visually-guided reaching and grasping (Cavina-Pratesi et al. 2010). This anatomical proximity raises a key question: Does SPL form a navigation-related system distinct from neighboring reaching and grasping-related cortex, or are both regions part of a broader parietal network for visually guided action?

The distinction is critical, as SPL and SPOC (as well as some other parietal areas) are labeled as “action selective,” yet few studies have directly compared different action types within the same participants. In fact, most existing evidence comes from single-action paradigms or meta-analyses identifying activation patterns for individual actions, without directly contrasting them to test for functional specificity

(Gallivan et al. 2009; Sulpizio et al. 2023; Yoon et al. 2025). Consequently, the functional boundaries between these parietal action regions remain largely inferential rather than empirically delineated.

To directly test then whether SPL and SPOC are empirically delineated, we used a within-subject functional magnetic resonance imaging (fMRI) design and investigated the response profiles of SPL and SPOC on both visually guided navigation and reaching and grasping stimuli. More specifically, participants viewed 3-s video clips from four conditions that varied in the type of visually guided action: (1) dynamic scenes depicting first-person motion through scenes (mimicking the actual visual experience of navigating through a scene), (2) static scenes with no first-person perspective motion (stills taken from the Dynamic Scenes condition, rearranged to eliminate motion cues), (3) first-person reaching and grasping performed on a scene background, and (4) the same first-person reaching and grasping now performed against a black background. If SPL is specialized for visually-guided navigation, it should respond more strongly to i) dynamic scenes than static scenes, consistent with its proposed role in visually-guided navigation, and ii) dynamic scenes than to reaching and grasping actions, even when those reaching and grasping actions occur within a scene background. Conversely,

Received: December 19, 2025. **Revised:** March 12, 2026. **Accepted:** March 27, 2026

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if SPOC is specialized for visually-guided reaching and grasping, it should show the exact opposite pattern, responding more to visually-guided reaching and grasping than navigation stimuli. Such a double dissociation would provide strong evidence for two distinct parietal systems: one for visually-guided navigation and another for visually-guided reaching and grasping.

In addition to task-based fMRI, we also examined resting-state functional connectivity to assess whether SPL and SPOC show differential intrinsic coupling with motor cortex regions. Specifically, we tested whether SPL connects preferentially with the portion of the primary motor cortex involved in leg movements (“leg-motor cortex”)—consistent with its proposed role in visually-guided navigation—and whether SPOC connects more strongly with the portion of the primary motor cortex involved in arm movements (“arm-motor cortex”), aligning with its role in visually-guided reaching and grasping. Demonstrating this kind of effector-specific connectivity would provide convergent evidence that these neighboring parietal regions indeed support distinct visually guided actions.

Materials and methods

The current study consisted of four fMRI components conducted within a single scanning session: i) a navigation/reaching and grasping task that used a split-half design to identify SPL and SPOC, as well as three other scene-selective regions—OPA, parahippocampal place area (PPA), and retrosplenial complex (RSC); ii) a category localizer to independently identify scene-selective regions to validate their anatomical correspondence with those defined by the main experimental task, and moreover to identify an object-selective region, lateral occipital complex (LOC) as a control region; iii) a motor localizer to define leg- and arm-motor cortices; and iv) a resting-state scan to assess intrinsic functional connectivity between SPL/SPOC and leg/arm motor cortices.

Participants

Nineteen healthy adults were recruited for this experiment. All participants gave informed consent. All participants had normal or corrected-to-normal vision and had no history of neurological or psychiatric conditions. Two participants were excluded because we could not identify scene-selective regions and SPOC from the localizers. Thus, we report the results from 17 participants (14 females; ages 20 to 32; $M = 23.29$, $SD = 3.02$). Of the 17 participants included in the analyses, 16 were right-handed and one reported being ambidextrous, although their Edinburgh Handedness Inventory score indicated left-handedness ($M = 0.83$, $SD = 0.35$, where +1 indicates a “pure” right-hander and –1 a “pure” left-hander; Oldfield 1971). Participants were compensated upon completing the study. All procedures were approved by the Emory University Institutional Review Board.

Design and stimuli

Navigation/reaching and grasping task

We defined SPL, OPA, PPA, RSC, and SPOC using half of the task runs (either odd or even runs) and examined their responses using the remaining held-out runs, following a region of interest (ROI) approach described in the Data Analysis section. For all runs, we used a blocked design in which participants viewed stimuli from four conditions: Dynamic Scenes, Static Scenes, Contextual Reaching and Grasping,

and Isolated Reaching and Grasping (Fig. 1). For each of the Dynamic Scenes, Contextual Reaching and Grasping, and Isolated Reaching and Grasping conditions, there were 48, 3-s video clips, subtending 23×15 degrees of visual angle. The Dynamic Scenes stimuli portrayed first-person perspective motion, as one would experience from walking through a place (Kamps et al. 2016; Yoon et al. 2025). Indeed, the video clips were filmed by walking through 8 different places (e.g. a parking garage, a hallway) at a typical pace with a camera (a Sony HDR XC260V HandyCam with a field of view of 90.3×58.9 degrees) held at eye level. The Static Scenes stimuli were created by taking stills from each Dynamic Scenes video clip at 1-, 2-, and 3- time points, resulting in 144 images. These still images were presented in groups of three images from the same video clip, and each image was presented for 1 s with no interstimulus interval (ISI), thus equating the presentation time of static images with the duration of video clips from which they were made (still totaling 3 s). Importantly, the still images were presented in a quasi-random sequence such that first-person perspective motion could not be inferred, and the images were never shown in their original temporal order. Like the video clips, the still images also subtended 23×15 degrees of visual angle.

The Contextual Reaching and Grasping stimuli portrayed a first-person reaching and grasping motion, as one would experience from using one’s right arm and hand to reach out for and grasp an object. Indeed, the video clips were filmed by reaching out for and grasping 48 different objects (e.g. a purse, a bottle) placed on a desk against a wall, at a typical pace with a camera (a GoPro HERO9 5 K UHD 2880p Action Camera with a field of view of 87×56 degrees) held at eye level. Lastly, the Isolated Reaching and Grasping stimuli portrayed the same reaching and grasping motion, but against a completely black background so that there is no scene layout information. Everything in the background including the desk were covered with a green screen backdrop, which were later completely blacked out using Adobe Premiere Pro (Adobe Inc., 2024).

Fourteen of the 17 participants completed 6 runs including all four conditions (Dynamic Scenes, Static Scenes, Contextual Reaching and Grasping, and Isolated Reaching and Grasping) while three participants completed 6 runs including three of the four conditions (Dynamic Scenes, Contextual Reaching and Grasping, and Isolated Reaching and Grasping) since the Static Scenes condition was added only after scanning the first three participants.

Category localizer

To validate the anatomical locations of scene-selective regions defined with the navigation/reaching and grasping task, we conducted a separate category localizer scan, as previously described (Jones et al. 2023; Yoon et al. 2025). Each participant completed 2 runs of the localizer. Each run was 312 s long and consisted of 3 blocks per stimulus category. Each block contained six 3-s video clips from a single category: the “Scenes” condition showed first-person motion through scenes; “Faces” showed children’s faces against a black background as they laughed, smiled, or looked around; “Objects” showed toys moving against a black background; and “Scrambled Objects” showed video clips from the Objects condition divided into a 20×20 grid, with the grid tiles randomly reordered to scramble the video. The order of stimulus category blocks in each run was palindromic (e.g. Faces, Objects, Scenes, Scrambled Objects, Scrambled Objects, Scenes, Objects, Faces). Each run also included four 12-s fixation blocks: one at the beginning, one in the middle, and one at the end.

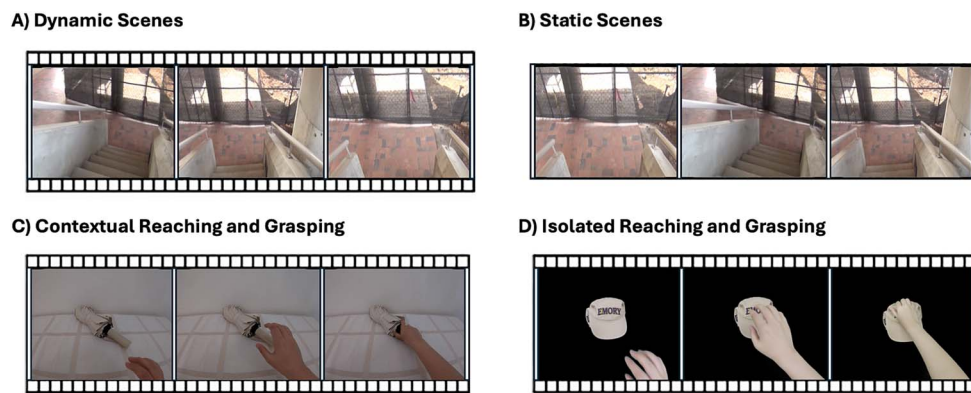


Figure 1 Example stimuli. The conditions included A) dynamic scenes, which consisted of 3-sec video clips of first-person perspective motion walking through a scene; B) static scenes, which consisted of three 1-sec stills taken from the dynamic scenes condition and presented in a quasi-random order, such that first-person perspective motion could not be inferred; C) contextual reaching and grasping, which consisted of 3-sec video clips of first-person perspective motion portraying a person's right arm reaching out for and grasping an object placed on a desk; D) isolated reaching and grasping, which consisted of 3-sec videos of the same reaching and grasping motion but now against a completely empty background.

This category localizer allowed us to determine whether the regions identified with the Dynamic Scenes > Reaching and Grasping contrast in the main navigation/reaching and grasping task corresponded spatially to those defined with the conventional Scenes > Objects contrast (i.e. SPL, OPA, PPA, and RSC). We were also able to identify object-selective region LOC with the Objects > Scrambled Objects contrast for comparison against SPOC in a control analysis.

Motor localizer

We used a simple motor localizer scan to define each participant's arm- and leg-motor cortices. The localizer used a blocked design with four movement conditions: Left Leg, and Right Leg, Left Arm, Right Arm. Each participant completed two runs of the localizer scan. Each run lasted 150 s and contained 11 blocks in total: 8 movement blocks (2 each of Left Leg, Right Leg, Left Arm, Right Arm) and 3 fixation blocks, one at the beginning, one in the middle, and one at the end of the run. The order of movement conditions was pseudorandomized to avoid sequence bias.

Each movement block began with a 3-s cue showing a leg or arm image on the left or right side of fixation, indicating which limb to move (e.g. a leg image to the left of fixation signaled "Left Leg"). The cue was followed by an 8-s movement period during which participants lifted the indicated limb once per second in response to the central fixation dot flashing red. Fixation blocks (6 s each) contained only the static black fixation dot.

Resting-state scan

For the resting-state scan, each participant completed a 6-min scan where they were instructed to close their eyes and to not think about anything in particular while refraining from falling asleep.

fMRI scanning

All scan sessions were carried out using a 3 T Siemens MAGNETOM Prisma scanner in the Facility for Education and Research in Neuroscience (FERN) at Emory University (Atlanta, GA). Functional images were acquired using a 32-channel head matrix coil and a Center for Magnetic Resonance Research (CMRR), Department of Radiology, University of Minnesota multiband accelerated EPI sequence (60 slices, TR = 2 s, TE = 30 ms, voxel size = $2.0 \times 2.0 \times 2.0$ mm, multiband acceleration factor = 2) (Xu et al. 2013). For all scans, slices were

acquired parallel to the anterior-posterior commissure line, covering all the occipital and parietal lobes, as well as most of the temporal lobe. Whole-brain, high-resolution T1w images were also acquired for each participant for purposes of registration and anatomical localization.

Data analysis

Navigation/reaching and grasping task

fMRI data analysis was conducted using the Analysis of Functional NeuroImages (AFNI) software (Cox 1996; Cox and Jesmanowicz 1999) (version 20.3.02) software. Prior to statistical analysis, images were motion-corrected using 3dVolreg and then spatially smoothed with a 6-mm kernel with 3dMerge. After preprocessing, scene-selective regions SPL, OPA, PPA, and RSC were bilaterally defined in participants by identifying regions that responded significantly more to Dynamic Scenes than both Contextual Reaching and Grasping and Isolated Reaching and Grasping ($p < 10^{-4}$, uncorrected) in half the data. All analyses in the Results section are performed on these ROIs using the remaining left-out half of the data (i.e. the data not used to define the localizers). The number of participants exhibiting each region in each hemisphere was as follows: lSPL: 16/17; lOPA: 17/17; lRSC: 16/17; lPPA: 16/17; rSPL: 17/17; rOPA: 17/17; rRSC: 15/17; rPPA: 16/17. Anatomically, SPL was located adjacent and anterior to the parieto-occipital sulcus as previously reported (Yoon et al. 2025) (Fig. 2).

Additionally, reach-selective regions, the superior parietal occipital cortex (SPOC), were also bilaterally defined in participants by identifying regions that responded significantly more to both Contextual Reaching and Grasping and Isolated Reaching and Grasping than Dynamic Scenes ($p < 10^{-4}$, uncorrected) in half the data. Left SPOC was successfully localized in 11 out of 17 participants, and right SPOC was successfully localized in 10 out of 17 participants. The relatively lower localization rate compared to prior studies likely reflects differences in task design. In previous work, participants interacted with or viewed physically reachable objects placed on a platform inside the MRI scanner, which strongly engaged reaching and grasping-related representations in SPOC (e.g. Gallivan et al. 2009). In contrast, the present experiment used passive video stimuli depicting reaching and grasping actions rather than executed or directly reachable movements. This passive observation design likely elicited weaker SPOC activation, reducing the number of participants in whom

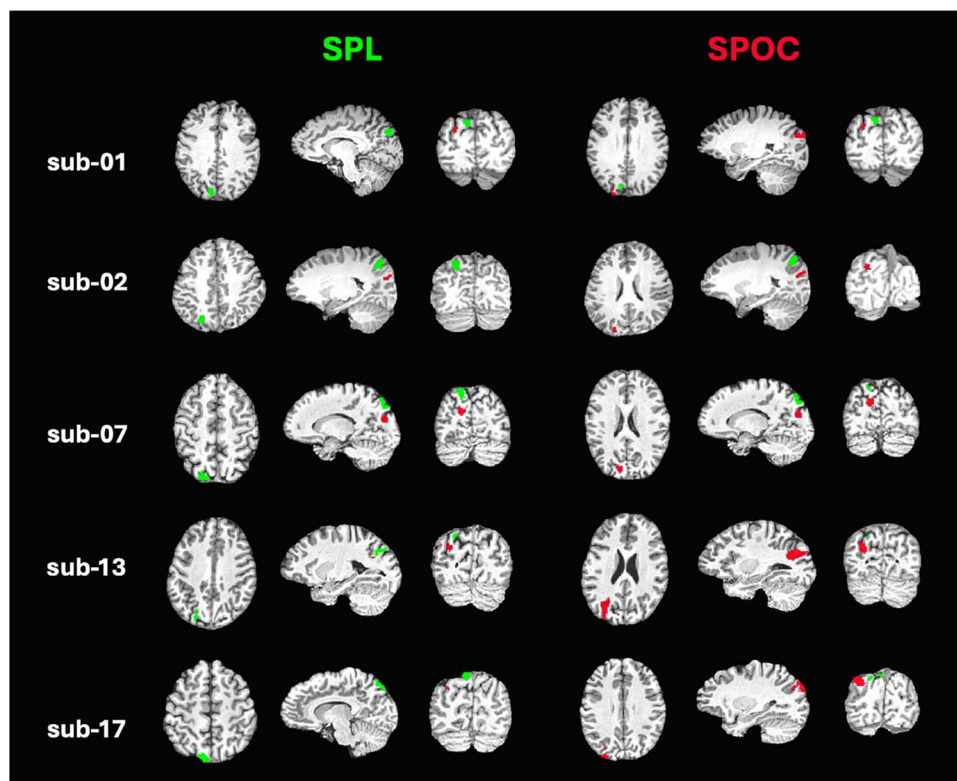


Figure 2 SPL (dynamic scenes > reaching and grasping) and SPOC (reaching and grasping > dynamic scenes) shown in the axial, sagittal and coronal imaging planes as identified in the left hemisphere of five representative subjects (SPL in the left column; SPOC in the right column). SPL is generally located adjacent and anterior to the parieto-occipital sulcus whereas SPOC lies directly posterior to it. Mean MNI coordinates (x, y, z) for SPL and SPOC were as follows: Left SPL ($-16.4, -78.2, 49.2$), right SPL ($15.3, -74.4, 53.2$), left SPOC ($-21.4, -84.7, 34.3$), and right SPOC ($24.3, -77.0, 39.9$).

the region could be reliably localized. Anatomically, SPOC was located adjacent and posterior to the parieto-occipital sulcus as previously reported for SPOC (sometimes also referred to as pSPOC; Cavina-Pratesi et al. 2010), although perhaps slightly more lateral than previous described. Importantly, there was no overlap between SPOC and SPL across all participants.

Finally, to ensure that SPL and SPOC do not include any voxels that are part of V6, a retinotopic region suggested to be involved in general egocentric motion (Sulpizio et al. 2023), we defined V6 using the parcel from Glasser et al. (2016) and excluded any overlapping voxels between SPL and SPOC, SPL and V6, as well as SPOC and V6 in each participant. To quantify the spatial independence of our regions of interest, we computed the percentage of SPL and SPOC voxels that overlapped with V6 for each subject. For SPL, spatial overlap was non-existent for the majority of participants. Specifically, overlap was zero in 13 out of 16 subjects for the left hemisphere and 14 out of 17 subjects for the right hemisphere. Minimal to small overlap was found in the remaining three subjects: 4.55, 30.43, 12% for the left hemisphere, and 1.75, 2.15, 5% for the right hemisphere. Similarly, overlap between SPOC and V6 was absent in 8 out of 11 subjects in the left hemisphere and all 11 subjects in the right hemisphere. Minimal overlap was found in the remaining three subjects: 3.37, 11.11, 1.03% for the left hemisphere. These results confirm that the neural representations observed in SPL and SPOC are spatially distinct from those in area V6.

Next, for each ROI for each participant, the average response across voxels for each condition was extracted and converted to percent signal change relative to the fixation baseline. Statistical analyses on the percent signal changes in the ROIs were conducted using R (R Core Team, 2013) (version 2022 July 2) and JASP statistical software (JASP

Team, 2023) (version 0.17.1). Where appropriate, significant ANOVA main effects were followed up with post-hoc comparisons. To ensure a conservative statistical approach and control for Type I error, all post-hoc tests were corrected for multiple comparisons using the Holm-Bonferroni method.

Finally, a 2 (Hemisphere: Left, Right) $\times$ 6 (ROI: SPL, SPOC, OPA, PPA, RSC, LOC) $\times$ 4 (Condition: Dynamic Scenes, Static Scenes, Contextual Reaching and Grasping, Isolated Reaching and Grasping) repeated-measures ANOVA did not reveal a significant hemisphere by ROI by condition interaction [$F(15,90) = 0.99, p = .475$]; thus, data from each hemisphere were collapsed for all further analyses.

Category localizer

fMRI data analysis was conducted using the AFNI software (version 20.3.02). Prior to statistical analysis, images were motion-corrected using 3dVolreg and then spatially smoothed with a 6-mm kernel with 3dMerge. After preprocessing, SPL, OPA, PPA, and RSC were bilaterally defined by identifying regions that responded significantly more to Scenes than Objects ($p < 10^{-4}$, uncorrected). Bilateral SPL were each successfully identified in 16 out of 17 participants, and bilateral OPA, PPA, and RSC were identified in all 17 participants. The resulting ROIs were compared with those defined from the main navigation/reaching and grasping task to validate their anatomical correspondence. The anatomical locations of the two sets were comparable—demonstrating that the two sets of ROIs point to the same anatomical loci (Table S1). Finally, for a control analysis, object-selective region LOC, was identified with the Objects > Scrambled Objects contrast ($p < 10^{-4}$, uncorrected). Bilateral LOC was successfully defined in all 17 participants.

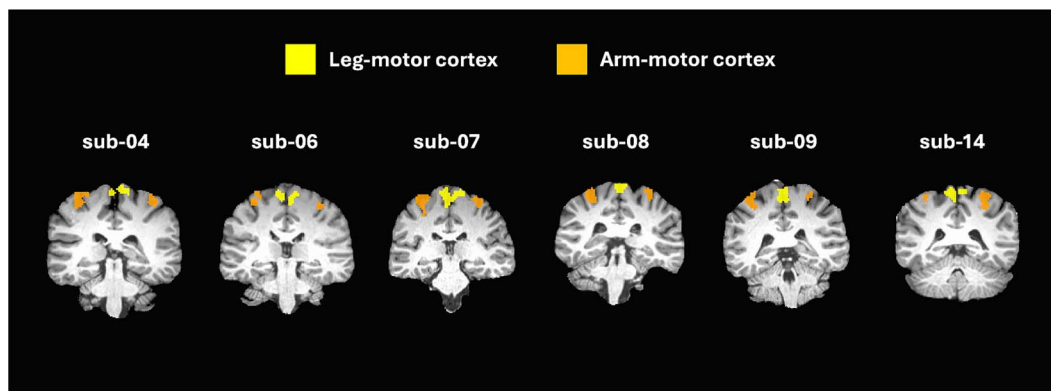


Figure 3 Leg-motor cortex and arm-motor cortex in primary motor cortex (M1) shown in the coronal imaging planes as identified in both hemisphere of six representative subjects (leg-motor cortex in yellow; arm-motor cortex in orange).

Motor localizer

The motor localizer data were analyzed using the same preprocessing and general linear modeling procedures described for the category localizer scans. Briefly, data were motion-corrected, spatially smoothed (4- and 6-mm FWHM), and analyzed in AFNI (version 20.3.02) using 3dDeconvolve. Each of the four movement conditions (Left Leg, Right Leg, Left Arm, Right Arm) was modeled as a separate regressor, with fixation modeled as baseline. Six motion parameters were included as nuisance regressors, and polynomial trends were removed. For each participant, contrasts comparing each movement condition to fixation (e.g. Left Leg > Fixation, Right Arm > Fixation) were computed to identify effector-specific motor regions (Fig. 3).

Resting-state scan

For the resting-state scan, fMRI data were first corrected for head motion using 3dvolreg (AFNI). Before motion correction, volumes with movement > 2 mm were corrected via interpolation between the nearest nonaffected volumes to reduce abrupt signal changes caused by head motion (3dDespike, AFNI). Temporal smoothing was performed to retain only low-frequency signals between 0.01 and 0.08 Hz. No spatial smoothing was applied. Nuisance regression was performed to remove motion artifacts (six motion parameter estimates) and the mean signal from a ventricular and white matter region. T1w image was registered to the middle image of the resting-state scan using align_epi_anat.py (AFNI).

After preprocessing, continuous time series data were extracted from all voxels within each ROI and averaged to obtain a mean time series per ROI. We then assessed intrinsic functional connectivity between SPL and SPOC and each of the motor regions (Leg and Arm) by computing Pearson correlations between their mean time series. To isolate connectivity specific to each parietal-motor pair, we performed partial correlation analyses, controlling for the time series from the remaining ROIs (e.g. when examining SPL–Leg connectivity, the time series from SPOC and Arm were partialled out). Correlation coefficients (r) were converted to Fisher's z values to yield normally distributed scores for subsequent statistical analyses.

Results

Double dissociation between visually-guided navigation versus reaching and grasping in SPL and SPOC

If SPL supports visually-guided navigation and not reaching and grasping, it should respond to first-person motion through scenes

(mimicking one's visual experience of walking through a place) rather than to first-person reaching and grasping motion. Consistent with this hypothesis, a 4-level repeated-measures ANOVA (Condition: Dynamic Scenes, Static Scenes, Contextual Reaching and Grasping, Isolated Reaching and Grasping) revealed a significant effect of condition [$F(1.89, 24.54) = 24.23, p < .001, \eta_p^2 = .65$; Greenhouse–Geisser corrected] (Fig. 4). Post-hoc contrasts then revealed SPL responded significantly more to i) Dynamic than Static Scenes—replicating previous findings (Yoon et al. 2025), ii) Static Scenes than either reaching and grasping condition—consistent with SPL's scene selectivity (Yoon et al. 2025), and iii) critically significantly more to Dynamic Scenes than to either reaching and grasping condition (main effect contrasts, all $p_{holm} < .001$). We report individual plots for each of our 11 participants whose SPL and SPOC were both identified in at least one hemisphere (Fig. S3).

By contrast, SPOC showed the complete opposite pattern. A 4-level (Condition: Dynamic Scenes, Static Scenes, Contextual Reaching and Grasping, Isolated Reaching and Grasping) repeated-measures ANOVA revealed a significant effect of condition [$F(3, 24) = 27.56, p < .001, \eta_p^2 = .79$], with SPOC responding significantly more to both Contextual Reaching and Grasping and Isolated Reaching and Grasping than to Dynamic Scenes (main effect contrasts, all $p_{holm} < .001$). SPOC also responded more to Dynamic Scenes than to Static Scenes ($p_{holm} = .023$), but this difference is likely due to the greater amount of motion energy in Dynamic Scenes—consistent with its action selectivity, albeit for its nonpreferred category—rather than any involvement in navigation-related processing. This pattern indicates that SPOC is specifically sensitive to reaching and grasping actions, irrespective of whether they occur within a scene or in isolation, consistent with its established role in visually-guided reaching and grasping (e.g. Gallivan et al. 2009; Cavina-Pratesi et al. 2010).

While the above findings suggest a double dissociation, is that really true? The answer is yes. Directly comparing the two ROIs, a 2 (ROI: SPL, SPOC) $\times$ 4 (Condition: Dynamic Scenes, Static Scenes, Contextual Reaching and Grasping, Isolated Reaching and Grasping) repeated-measures ANOVA revealed a significant interaction, with SPL responding more strongly to Dynamic Scenes than either Contextual Reaching and Grasping or Isolated Reaching and Grasping compared to SPOC (interaction contrasts, both $P_s < .001$). SPOC on the other hand, responded more strongly to Contextual Reaching and Grasping or Isolated Reaching and Grasping than Dynamic Scenes compared to SPL (interaction contrasts, both $P_s < .001$). Together, these findings reveal a double dissociation, with SPL responding to visually-guided

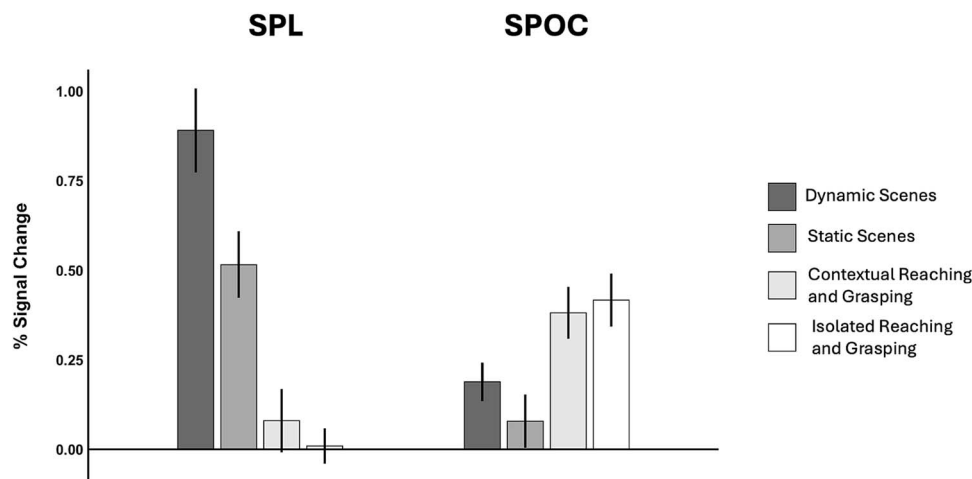


Figure 4 % signal change for dynamic scenes, static scenes, contextual reaching and grasping and isolated reaching and grasping conditions, labeled accordingly, in SPL and SPOC. Error bars reflect the standard error of the mean.

navigation, not reaching and grasping, stimuli, while SPOC shows the opposite pattern.

But would any scene/object-selective region show the same profile as SPL/SPOC? To directly address these possibilities, we first compared SPL to the other scene-selective regions, OPA, PPA, and RSC. A 4 (ROI: SPL, OPA, PPA, RSC) $\times$ 4 (Condition: Dynamic Scenes, Static Scenes, Contextual Reaching and Grasping, Isolated Reaching and Grasping) repeated-measures ANOVA revealed a significant interaction [$F(2.08, 22.86) = 3.68, p < .05, \eta_p^2 = .25$; Greenhouse–Geisser corrected], with SPL responding significantly more to Dynamic than Static Scenes compared to PPA and RSC (interaction contrasts, $p = .009, p = .006$, respectively), but importantly not OPA ($p = .126$) since OPA is also involved in visually-guided navigation (Kamps et al. 2016; Yoon et al. 2025) (Fig. 5). Secondly, we then compared SPOC to LOC, an object-selective region. A 2 (ROI: SPOC, LOC) $\times$ 4 (Condition: Dynamic Scenes, Static Scenes, Contextual Reaching and Grasping, Isolated Reaching and Grasping) repeated-measures ANOVA revealed a significant interaction [$F(1.39, 11.08) = 10.49, p = .005, \eta_p^2 = .57$; Greenhouse–Geisser corrected], with LOC responding significantly more to either reaching and grasping condition compared to Dynamic Scenes, relative to SPOC (interaction contrast, $P_s < .001$). While a no-object reaching and grasping condition would be needed to definitively isolate action selectivity from object selectivity, the more pronounced difference in LOC most likely stems from its robust object preference rather than action-related processing (Cavina-Pratesi et al. 2007; Culham et al. 2003; Valyear et al. 2006). Together, these results reveal that the action selectivity in SPL and SPOC cannot merely be explained by their category selectivity.

Finally, given that we did not precisely match the amount of low-level visual information across the experimental conditions, might it be the case that SPL and SPOC's action selectivity simply reflects differences in these features? To test this, we quantified four potential confounds for every video stimulus: motion energy (optical flow; Farneback 2003), visual complexity (sub-band entropy; Rosenholtz et al. 2007), mean depth (ratio of vertical to horizontal spatial orientation energy; Torralba and Oliva 2002), and spatial frequency (mid-to-high-frequency spectral energy; Bainbridge and Oliva 2015). Statistical analyses confirmed significant differences across experimental conditions for all four features; however, none of their distributions

matched the neural response patterns observed in SPL and SPOC. Furthermore, when we regressed out all four low-level features simultaneously, the double dissociation remained (see Fig. S1–S2).

SPL is preferentially connected to leg-motor cortex, SPOC to arm-motor cortex

Having shown that SPL and SPOC are functionally dissociable during task-based fMRI, we next asked whether these regions also show distinct intrinsic coupling patterns with motor cortex. If SPL and SPOC support separate visually guided action systems, we might expect their resting-state connectivity to also reflect this division: SPL should be preferentially connected to leg-motor cortex (leg M1), and SPOC to arm-motor cortex (arm M1), as humans typically use their legs to navigate and their arms to reach for objects.

To test this hypothesis, we calculated the pairwise correlations among SPL, SPOC, leg-, and arm-motor cortex, while partialing out the activation from the remaining ROIs, to assess the co-fluctuation between each pair of regions, above and beyond the shared responses among all four regions. To maximize the statistical power of our analysis, within-hemisphere (e.g. left SPL and left leg-motor) and between-hemisphere (e.g. left SPL and right leg-motor) correlations were averaged together for each pair of regions in each subject. Note that between-hemisphere correlations did not include homotopic connections (e.g. left SPL–right SPL).

As predicted, SPL showed stronger functional connectivity with leg-motor cortex than with arm-motor cortex ($t(10) = 2.318, p = 0.042, d = 0.783$), whereas SPOC showed stronger connectivity with arm-motor cortex than with leg-motor cortex ($t(10) = 3.57, p = .005, d = 1.12$) (Fig. 6). Critically, when we directly compared the connectivity profiles of SPL and SPOC, a repeated-measures ANOVA with visually guided action regions (SPL, SPOC) and motor regions (leg- and arm-motor cortex) as factors revealed a significant interaction between visually guided action and motor regions ($F(1,10) = 12.93, p = .005, \eta_p^2 = 0.56$), indicating that SPL and SPOC exhibit distinct connectivity profiles with the motor cortex. Again, we report individual plots for each of our 11 participants whose SPL and SPOC were both identified in at least one hemisphere (Fig. S4). Furthermore, to determine whether these distinct connectivity patterns differed by hemisphere, we conducted a 2

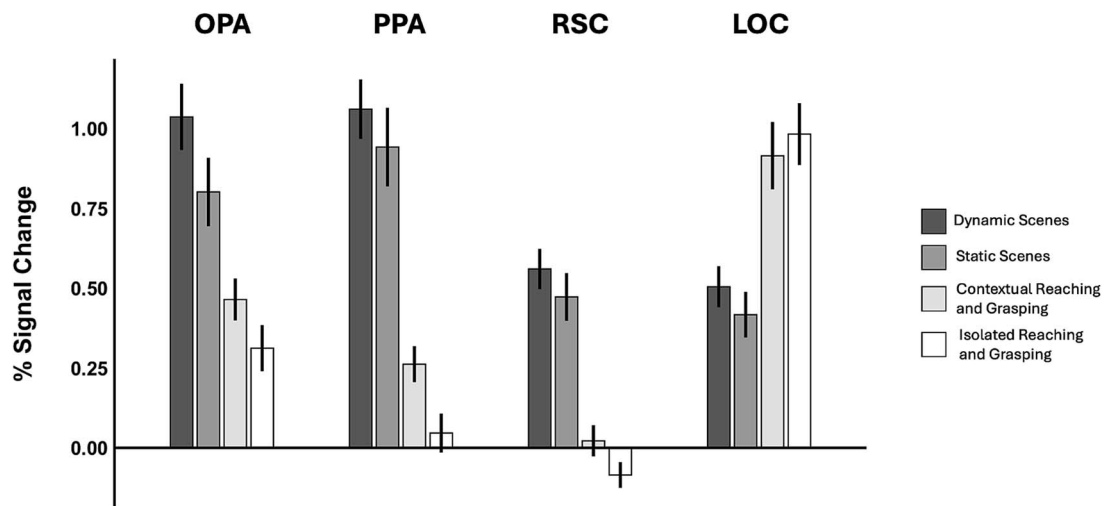


Figure 5 % signal change for dynamic scenes, static scenes, contextual reaching and grasping and isolated reaching and grasping conditions, labeled accordingly, in OPA, PPA, RSC, and LOC. Error bars reflect the standard error of the mean.

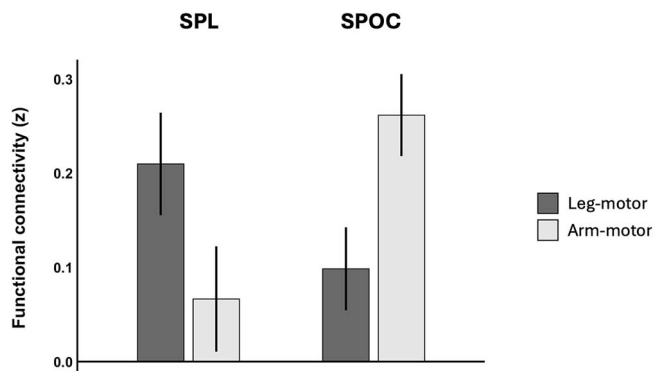


Figure 6 Functional connectivity between SPL and SPOC to leg- and arm-motor regions of the primary motor cortex. Error bars reflect the standard error of the mean.

(Hemisphere: Left, Right) $\times$ 2 (ROI: SPL, SPOC) $\times$ 2 (Motor Cortex: Arm, Leg) repeated measures ANOVA on the functional connectivity values. We did not find a significant interaction [$F(1, 7) = 0.16, p = .702, \eta_p^2 = .02$], revealing that the functional dissociation (SPL preferentially connected to Leg-motor cortex and SPOC to Arm-motor cortex) does not differ significantly between the left and right hemispheres. These distinct connectivity profiles reveal that SPL and SPOC are each functionally coupled to the motor effectors most relevant to their respective behavioral roles—visually-guided navigation and visually-guided reaching and grasping—and thus further support the existence of distinct visually guided action systems within the human parietal cortex.

Discussion

We report a non-overlapping, functionally discrete organization of the human parietal cortex, anchored in the motor effector required for a given action. Two adjacent dorsal regions—SPL and SPOC—form distinct visually guided action subsystems, each selectively coupled to a different effector. SPL, a region supporting visually-guided navigation, was strongly connected to the leg-motor cortex, whereas SPOC, implicated in visually-guided reaching and grasping, was strongly connected to the arm-motor cortex. These findings indicate that

neighboring parietal areas are differentiated not only by the type of visually guided action they support but also by their anchoring to specific effectors, suggesting an organization that is both anatomically and functionally specialized.

Previous human neuroimaging work suggested parietal subregions involved in different visuomotor actions (e.g. reaching, grasping, and eye movements) but emphasized their functional proximity and potential overlap, leaving open how sharply these representations are separated (Culham and Valyear 2006). Similarly, other research characterized “action-selective” activations using single-action paradigms only—and thus could not determine whether these patterns reflect distinct functional territories or graded representations (Gallivan et al. 2009; Sulpizio et al. 2023; Yoon et al. 2025). Our findings address these issues directly: Within the superior parietal cortex, representations for visually-guided navigation and reaching and grasping resolve into non-overlapping subregions with distinct effector coupling. SPL and SPOC form adjacent yet independent visually guided action systems, each preferentially linked to a distinct effector—leg or arm. This double dissociation suggests that effector-specific coupling, rather than shared or overlapping representations, defines the organizing principle of this portion of the dorsal stream.

The parietal cortex has long been viewed as part of a “vision-for-action” pathway that transforms visual input into motor commands for diverse behaviors (Goodale and Milner 1992). The present results elaborate on this framework by showing that vision-for-action is distributed across multiple, effector-tuned subsystems rather than mediated by a single, general-purpose controller. SPL makes up a leg-based visually-guided navigation module linking egocentric motion perception to locomotor control, while SPOC makes up an arm-based visually-guided reaching and grasping module linking visual target information to arm control.

Our findings also raise questions about the granularity of effector-specific representations. In our reaching and grasping condition, the stimuli depicted both reaching and grasping movements. Prior work suggests that these components (e.g. reaching, grasping, and even pointing) rely on partially distinct parietal subregions (Gallivan and Culham 2015; Cavina-Pratesi et al. 2018). Likewise, visually-guided navigation may also be divided into leg/trunk-related motion

supporting large-scale displacement and foot-related motion supporting fine-grained gait and balance control.

While the present results demonstrate a double dissociation between SPL and SPOC in both functional activation and resting-state connectivity, they remain correlational. Establishing causality will require neurostimulation or lesion-based approaches. For instance, temporary disruption of SPL should impair navigation-related tasks. This could be achieved using established techniques like transcranial magnetic stimulation (TMS) or emerging non-invasive methods like temporal interference (TI)—a technique that utilizes intersecting high-frequency electric fields to safely and focally stimulate deep brain structures (Grossman et al. 2017). Conversely, disruption of SPOC should yield optic-ataxia-like deficits in reaching and grasping (Vesia and Crawford, 2012). Complementary evidence from patient populations with focal parietal lesions could further elucidate how damage to each region affects specific visually guided actions.

Furthermore, it is important to consider how physical execution of an action relate to these distinct action systems. While our current study instructed participants to imagine performing the actions depicted from a first-person perspective, we would expect the same results if we asked participants to physically execute the actions for the following two reasons. First, motor imagery recruits the exact same neural circuitry as physical execution in the posterior parietal cortex, including SPL and SPOC (Andersen and Buneo 2002; Buneo and Andersen 2006; Gallivan et al. 2009; Fattori et al. 2012; Yoon et al. 2025; Zhang et al. 2025). Second, our effector-specific resting-state connectivity provides independent, task-free evidence that SPL and SPOC are intrinsically coupled to the leg- and arm-motor cortices, further supporting their roles as anchored action-guidance systems rather than purely visual observation regions.

But is SPL just PIGS (“posterior intraparietal gyrus scene-selective” site)—another recently reported parietal region claimed to be scene selective and sensitive to first-person motion through scenes (Kennedy et al. 2024)? The answer is no, both anatomically and functionally. First, anatomically, the two regions are distinct: PIGS sits in the posterior intraparietal gyrus, whereas SPL lies anterior to the parieto-occipital sulcus along the medial wall. Second, functionally, PIGS, unlike SPL, is neither scene-selective nor sensitive to first-person motion through scenes. Specifically, Kennedy et al. defined PIGS using Scenes > Faces and Scenes > Faces/Objects/Scrambled contrasts rather than the established Scenes > Objects contrast that reliably isolates scene-selective cortex, and the furniture-rich “object” images used in their localizer further blurred the distinction between scenes and objects. In our analyses using their parcels in our previous dataset (Yoon et al. 2025), PIGS responded more to dynamic scenes than to dynamic faces or objects but responded similarly between static scenes and static objects—a pattern unlike SPL and traditional scene-selective regions (Fig. S5).

Moreover, when we directly compared SPL to PIGS in the current study, there was a significant ROI by conditions interaction, with SPL responding significantly more to Dynamic than Static Scenes, as well as Dynamic Scenes than either reaching and grasping condition, relative to PIGS (Fig. S6). Furthermore, SPL also responded significantly more to Static Scenes than either reaching and grasping condition, compared to PIGS.

Finally, how do our functionally defined regions map onto other nomenclatures of the medial posterior parietal cortex? Sulpizio et al. (2023) recently summarized several functional zones in this area, including V6Ad, V6, and PEc. Our functionally defined SPL closely

overlaps with the coordinates for V6Ad at $\pm 14, -72, 51$. However, whereas Sulpizio et al. (2023) characterize V6Ad as an upper-limb region for hand actions, our SPL region connects preferentially to the leg-motor cortex and is strongly selective for visually-guided navigation. The leg-related region in their framework is PEc, but PEc is located much further anterior at $\pm 12, -55, 64$. Meanwhile, our reach-selective SPOC region falls near the y and z coordinates of V6 or V6Av, but is located slightly more laterally. Furthermore, while V6 is primarily characterized as a visual or optic-flow region (Sulpizio et al. 2023), SPOC is highly selective for reaching and grasping actions. Together, these spatial and functional distinctions highlight the importance of using functionally defined localizers to accurately isolate these adjacent, but distinct, visually guided action systems.

Together, these findings suggest that the superior parietal cortex is organized around the behavioral demands of distinct effectors. SPL forms a subsystem for visually-guided navigation, linking visual cues to leg-motor control, whereas SPOC forms another subsystem for visually-guided reaching and grasping, linking target localization to arm-motor control. This effector-anchored, non-overlapping organization refines the traditional vision-for-action framework, showing that the dorsal stream is not a single pipeline for action guidance but a set of specialized, motor-anchored subsystems. In this sense, just as the ventral stream transforms visual input into perceptual categories, the dorsal stream transforms it into action-specific codes, each tailored to a different way of moving through and acting upon the world.

Acknowledgments

We would like to thank the Facility for Education and Research in Neuroscience (FERN) Imaging Center in the Department of Psychology, Emory University, Atlanta, GA. We would also like to thank Yujingai (Emmy) Shi for her assistance in stimuli generation and data collection, and Jody Culham for valuable advice and insightful discussions.

Author contributions

Hee Kyung Yoon (Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing—original draft, Writing—review & editing), Yaelan Jung (Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing—original draft, Writing—review & editing), and Daniel D. Dilks (Conceptualization, Funding acquisition, Investigation, Methodology, Validation, Project administration, Supervision, Writing—review & editing).

Supplementary material

Supplementary material is available at *Cerebral Cortex* online.

Funding

This work was supported by grants from the National Eye Institute (R01 EY29724 to D.D.D.) and the Facility for Education and Research in Neuroscience (FERN) Education Grant.

Conflicts of interest

None declared.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval disclosure statement

This study was approved by the Institutional Review Board at Emory University under approval number IRB00069592. All participants provided informed consent prior to participation.

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