Supporting Information

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SI Methods

Apparatus. Head-fixed animals sat in a custom-designed monkey chair (Crist Instrument) with a fully open front to allow unimpaired reaching movements. Visual stimuli were back-projected by an LCD projector onto a translucent screen mounted vertically, 40 cm in front of the animal. Eye position was monitored using the 120 Hz ISCAN eye-tracking laboratory (ETL-400). Touches were monitored every 2 ms using capacitive sensors, one at each starting arm position (home pad) and one at each reach endpoint. Reach endpoints on the vertical screen were organized in a virtual 3 × 3 grid centered on a central fixation point, forming a square 14 cm on each side. A 3 × 1.5 in transparent vertical divider bisected each target location. Animals were trained to reach with the left hand to the left side of the divider and with the right hand to the right side of the divider. Capacitive sensors were mounted behind the projection screen, ∼1 in to the right and left of each Plexiglas divider. As a result, the left and right hands activated unique sensors even when both hands reached toward the same target. Animals were continuously monitored using remote cameras as an additional check that the reaches were performing the tasks properly.

Electrophysiological Recordings. Single-unit recordings were made from all four hemispheres in two adult male rhesus monkeys. Recording chambers were placed flush to the skull and centered 6–8 mm posterior to the ear canals and 12 mm lateral of the midline. Anatomical magnetic resonance images were used to localize the IPS. Extracellular recordings were made from both banks of the sulcus using glass-coated tungsten electrodes (electrode impedance 0.5–3.0 M Ω; Alpha Omega). While searching for cells, animals performed interleaved saccade-only and contralateral arm-reach trials. After isolating a single cell, we identified its preferred direction or RF based on the target location that evoked the highest delay-period activity. If the preferred direction was not obvious from the two movement types, then data from up to five trials each of all five movement types (and eight peripheral target locations) were collected. The null direction was defined as the target direction 180° from the preferred direction. Data were then collected for preferred- and null-direction targets for all five movement types and either two or eight target locations for a median of 150 trials per cell (range: 22–400 trials).

We identified LIP as that region of cortex containing a high proportion of visually responsive cells with delay-period activity that was roughly similar for saccade-only compared with saccade-plus-reach trials. Anatomical reconstructions demonstrate that the tracks containing such cells were limited to the lateral bank of the IPS, extended longitudinally along the sulcus from about one-fourth of the way from the posterior junction with the parieto–occipital sulcus to about halfway to the anterior end of the sulcus (Fig. 1*B*, red cells). We identified PRR as that region of cortex containing a high proportion of visually responsive cells with delay-period activity that was greater for reach-plus-saccade trials than for saccade-only trials. Anatomical reconstructions demonstrate that the tracks containing such cells were located primarily, but not exclusively, on the medial bank of the caudal portion of the IPS (Fig. 1*B*, blue cells).

We collected responses of 103 isolated cells in PRR (41 in M1 and 62 in M2) and 71 in LIP (25 in M1 and 46 in M2). We collected data from all cells that we encountered with sustained delay activity for at least one trial type. We then sorted cells based on their location within LIP or PRR, as described in the previous paragraph. Thus, although the boundaries of LIP and PRR were based on the functional properties of the preponderance of cells, cells with properties that did not match the archetypal LIP or PRR cell were not excluded. For example, for 37 of the 103 PRR cells, delay-period responses for saccade-plus-reach trials were not significantly different from (31 cells) or were even less than (six cells) responses for saccade-only trials. Similarly, for 12 of 71 LIP cells, delay-period reach-plus-saccade responses were significantly greater than delay-period saccade-only responses. The presence of such cells is consistent with previous recordings from these areas (3, 4). Offline, cells were excluded if the preferred and null directions could not be clearly identified ($n = 8$) or if the firing rate averaged over the entire delay period was below 5 sp/s in PRR or was below 2.5 sp/s in LIP for all five trial types ($n = 13$). The results reported here are from the 89 remaining cells in PRR (37 in M1 and 52 in M2) and 64 cells in LIP (21 in M1 and 43 in M2). Two of 19 cells were excluded from the target-blanking dataset either because the preferred and null directions could not be unequivocally determined or because they had low maximum firing rates.

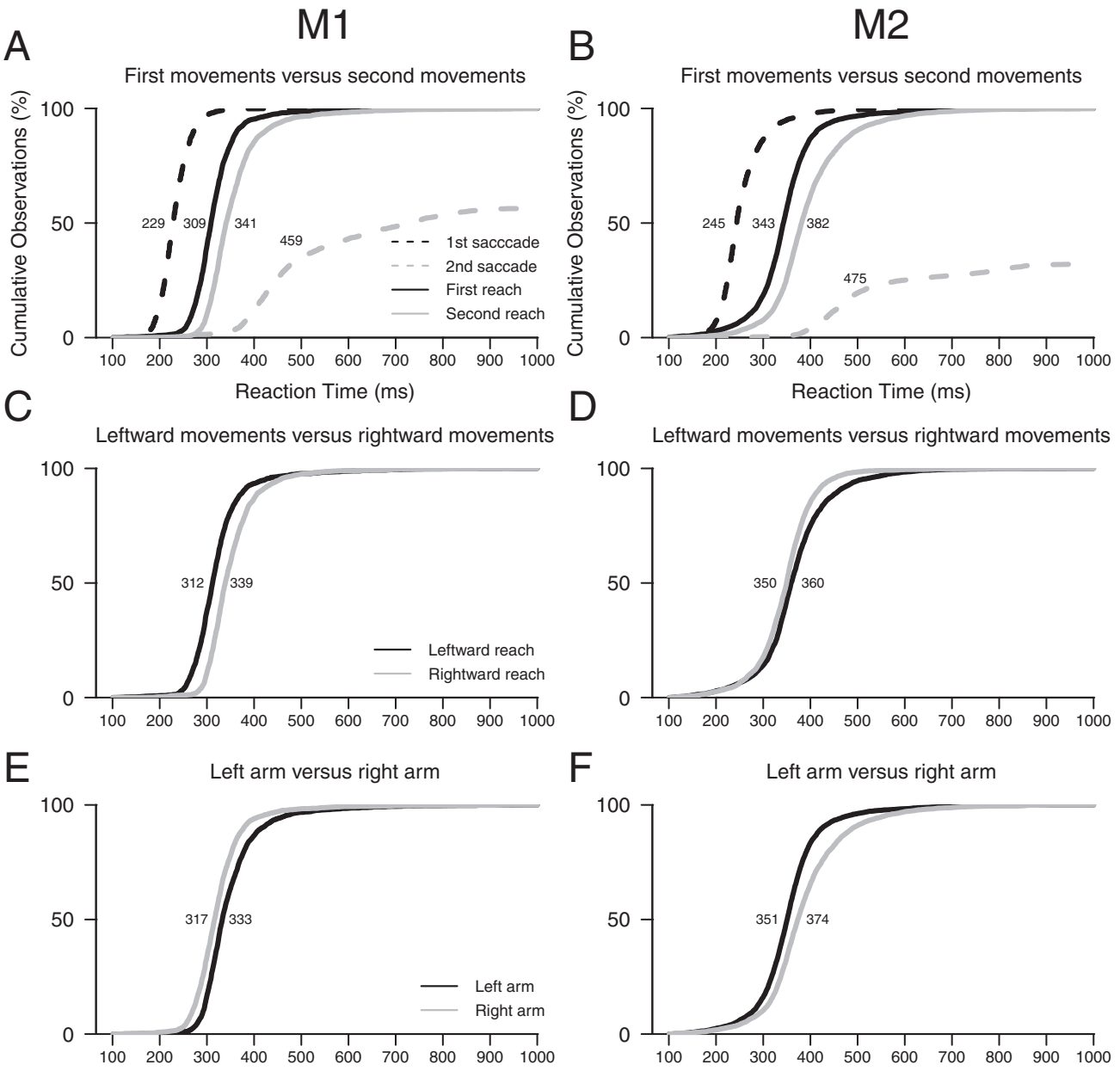

Fig. S1. Cumulative distributions of the reaction time for saccades and reaches for M1 (*Left*) and M2 (*Right*). The *x* axis shows time relative to the go cue. The *y* axis shows the cumulative percentage of trials in which the saccade or reach had been initiated. (*A* and *B*) Saccade and reach timing sorted by movement order. The first saccade (dashed black trace) occurred before either the first (solid black trace) or second (solid gray trace) arm movement. A second saccade (dashed gray trace) occurred on 56% of trials in an average of 227 ms. The two reaches were initiated close together in time (median difference: 32 ms in M1 and 39 ms in M2). (*C* and *D*) Reaches are sorted by movement direction. There was little bias for movements in one direction to be initiated sooner than movements in the other direction. (*E* and *F*) Reaches sorted by arm identity. Differences in initiation times were again small. Values on the plots indicate the median reaction time in milliseconds for each trace.

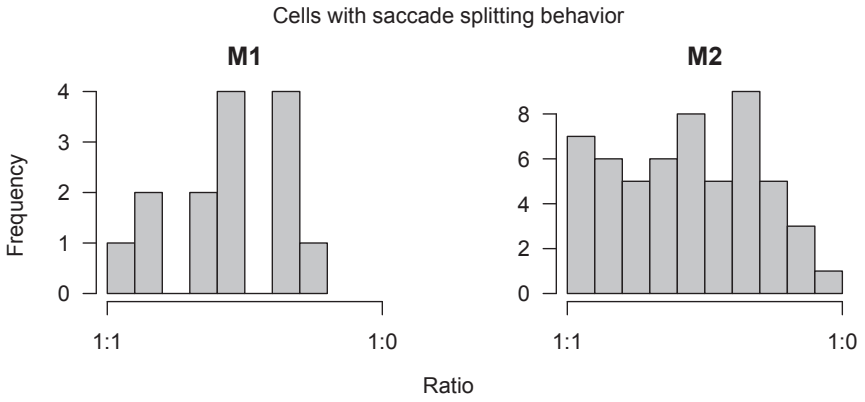

Fig. S2. Ratios of saccade directions for each cell with at least two trials containing saccades in each direction. Directional biases vary by cell. A ratio of 1:1 indicates even numbers of saccades in each direction (unbiased). A ratio of 1:0 indicates stereotyped saccade behavior. M1, $n = 14$ cells; M2: $n = 55$ cells.

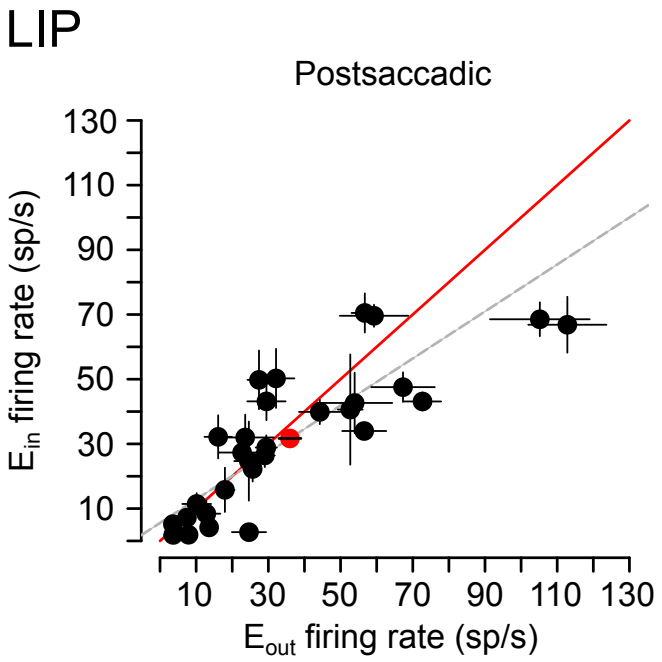

Fig. S3. (Related to Fig. 3.) Scatterplot of postsaccadic firing rates of LIP cells shown in Fig. 3*B* for E_{in} vs. E_{out} bimanual-apart reaches. Each point represents data from a single cell in the interval 50–150 ms after saccade onset. Error bars indicate the SEM. The unity line is in red. The dashed gray line is a type-II regression line.

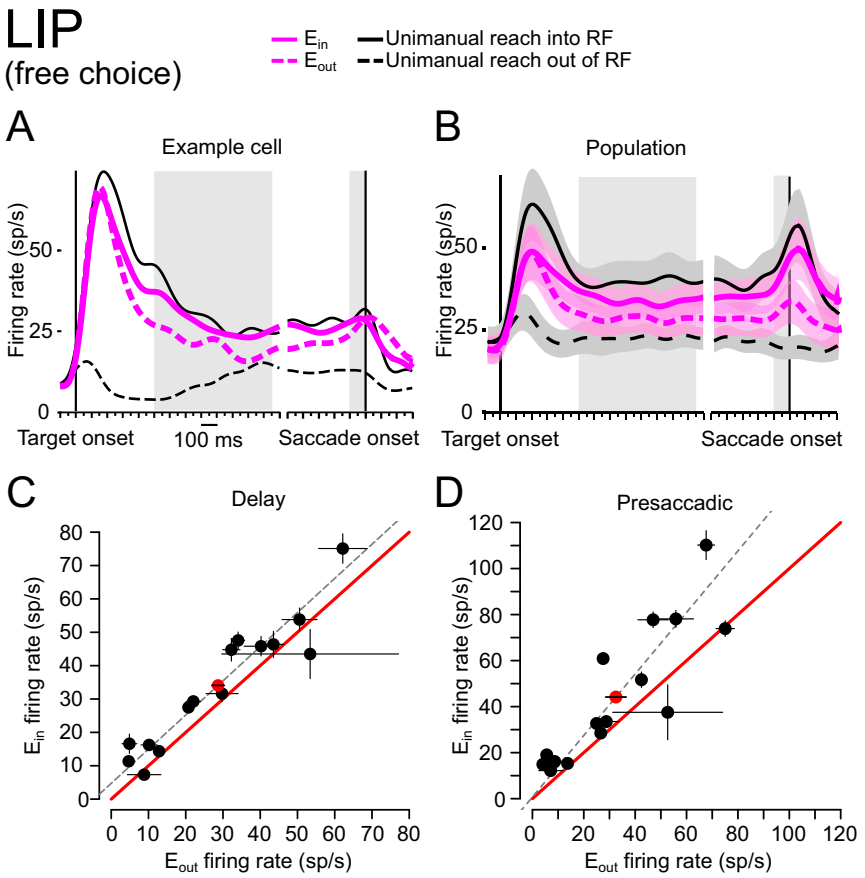

Fig. S4. (Related to Fig. 3.) Effect of freely chosen saccade direction on LIP activity. Data are shown from one animal (M1) that performed a free-choice delayed-saccade task. In the task, two stimuli appeared, one in the RF and one out of the RF. After the delay period, the animal was free to saccade to either target. Free-choice trials were randomly interleaved with single-target saccade trials in 12 of the 15 cells. The format is the same as in Fig. 3. (*A*) Responses of an exemplary LIP cell from the free-choice saccade task. (*Left*) Responses were higher when the monkey chose to saccade to the target in the RF (E_{in}: solid magenta, $n = 121$ trials, 27.50 ± 1.28 sp/s) than to the target out of the RF (E_{out}: dashed magenta trace, $n = 79$ trials, 20.73 ± 1.49 sp/s; Wilcoxon rank-sum test, $P = 0.01$). (*Right*) This was also true immediately before the saccade (E_{in}: 28.53 ± 1.18 sp/s; E_{out}: 26.61 ± 1.79 sp/s; Wilcoxon rank-sum test, $P < 0.001$). Similarly, and as expected, activity was high for a directed saccade into the RF during the delay and presaccadic periods (solid black trace: $n = 50$, 29.93 ± 1.87 sp/s and 30.22 ± 2.00 sp/s, respectively). Activity was low for a directed saccade out of the RF during the delay and just before the saccade (dashed black trace: $n = 50$, 9.45 ± 1.58 sp/s and 12.74 ± 1.84 sp/s, respectively). (*B*) Population activity of LIP cells for the free-choice task. Responses were higher for the E_{in} than for the E_{out} saccade direction ($n = 15$ cells; Wilcoxon sign rank test: delay, 34.08 ± 5.08 versus 28.67 ± 4.97 sp/s; $P = 0.005$; presaccadic, 44.17 ± 7.99 versus 32.51 ± 6.20 sp/s; $P = 0.009$). (*C* and *D*) Scatterplots of the firing rates for E_{in} vs. E_{out} saccades of the cells shown in *B*. Each point represents a single cell. Thirteen of the 15 cells showed greater activity in the E_{in} than in the E_{out} condition during the delay period (seven cells with $P < 0.05$) and immediately before the saccade (nine cells with $P < 0.05$). Error bars indicate the SEM. The unity line is in red. The dashed gray line is a type-II regression line. Animals moved their eyes to the second target immediately after the first saccade in 7.1% of trials, which was less than in the bimanual-apart paradigm. This difference does not explain the difference in E_{in} and E_{out} responses for the two tasks. Data obtained in the four runs with the highest rates of second saccades (24, 22, 18, and 14%) show the same difference in firing rate as the remaining cells (9% or less), indicating that a greater propensity to make a second saccade to the alternative target does not lead to a greater difference in firing rate for E_{in} versus E_{out} choices (difference of 5.42 sp/s for the four cells with the highest rates versus 5.41 for the remaining cells).

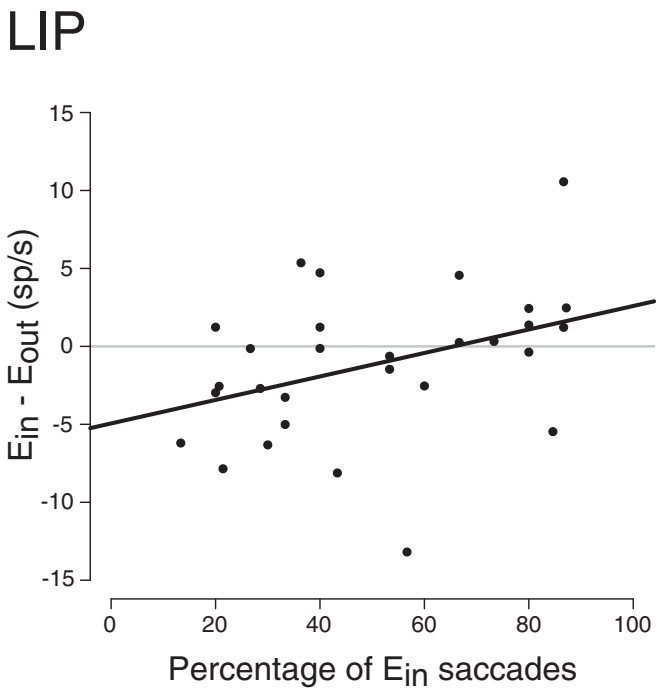

Fig. S5. Difference in firing rate between saccades into versus out of the RF (E_{in} minus E_{out}) as a function of the percentage of saccades directed into the RF (E_{in}) on bimanual-apart trials in LIP. Each point represents delay-period activity from a single cell. The black line indicates the linear fit ($P = 0.04$). It is important to emphasize that this does not directly encode whether a saccade has been made into or out of the field on any one trial. Also note that, for the configuration in which the animal is more likely to make a saccade out of rather than in the RF, activity will be higher for E_{out} trials than for E_{in} trials, just the reverse of what one would expect.

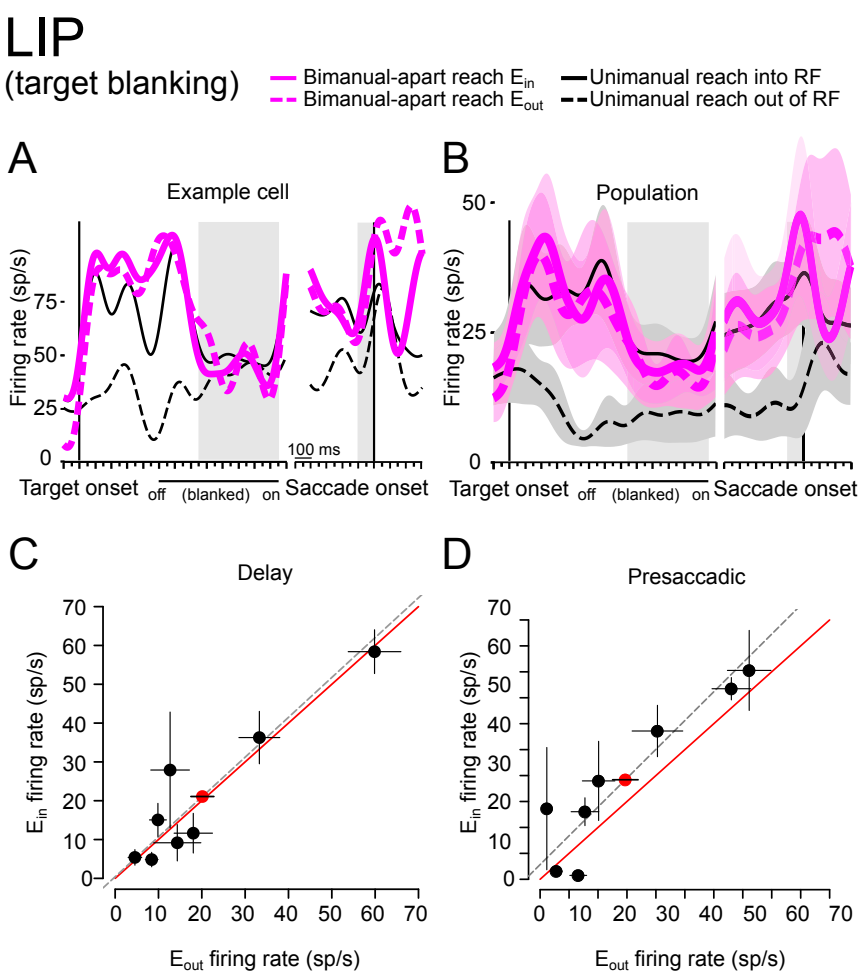

Fig. S6. (Related to Fig. 3.) Effect of target blanking on LIP memory activity. Data from one animal (M2) that performed target-blanking versions of the delayed-movement tasks. In these tasks, the visual stimulus disappeared for 750 ms during the delay period. The format is the same as in Fig. 3. (*A*) Responses of an exemplary LIP cell from the target-blanking task. Responses did not vary as a function of saccade direction ($n = 6$ E_{in} trials and 9 E_{out} trials; Wilcoxon rank-sum test: delay, $P = 0.24$; presaccadic, $P = 0.24$). (*B*) Population activity of LIP cells for the target-blanking task. Data are from all cells for which there were at least two trials of each saccade direction. Responses did not vary as a function of saccade direction ($n = 8$ cells; Wilcoxon sign rank test: delay, $P = 1.00$; presaccadic, $P = 0.11$). (*C* and *D*) Scatterplots of the firing rates for E_{in} vs. E_{out} saccades of the cells shown in *B*. Each point represents a single cell in the delay period (*C*) and presaccadic period (*D*). Error bars indicate the SEM. The unity line is in red. The dashed gray line is a type-II regression line.

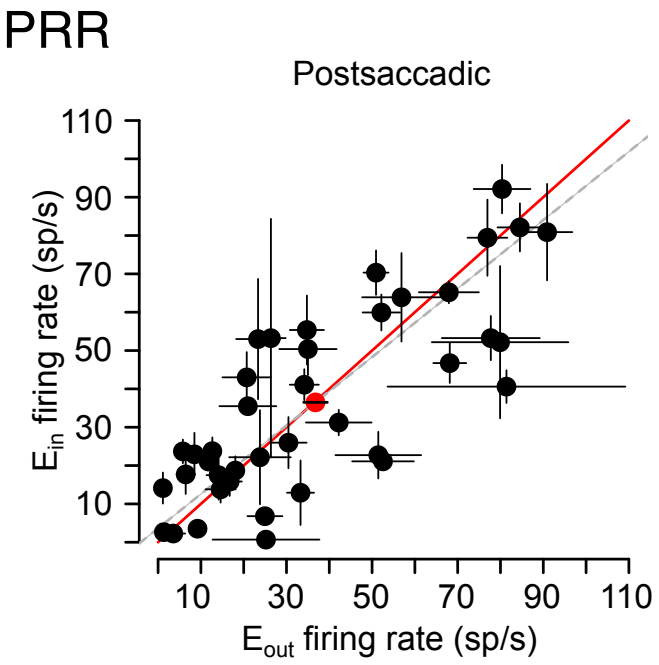

Fig. S7. (Related to Fig. 4.) Scatterplot of the postsaccadic firing rates for E_{in} vs. E_{out} bimanual-apart reaches of PRR cells shown in Fig. 4*B*. Each point represents data from a single cell in the interval 50–150 ms after saccade onset. Error bars indicate the SEM. The unity line is in red. The dashed gray line is a type-II regression line.

Table S1. Percentage of trials in which the left or right hand moved first, moved toward the left or right, and was accompanied by an initial saccade directed to the left or right

			Movement instruction and hand that moved first			
			Right hand moved to right		Right hand moved to left	
Animal	First saccade direction, %	Total, %	Right hand moved first, %	Left hand moved first, %	Right hand moved first, %	Left hand moved first, %
M1	Left	67	15	1	32	19
	Right	33	6	0	17	10
M2	Left	42	7	4	19	12
	Right	58	11	28	0	19

Values are the percentage of saccade choices to the left or right as a function of target location and reach order, averaged across all cells. Behavior was neither perfectly stochastic nor perfectly deterministic. For each animal, there are eight possible combinations of arm configuration (right hand to right and left hand to left, or vice versa), which hand (right or left) moves first, and saccade direction (right or left). If behavior were completely stochastic, the total percentages of left and right saccades would each be 50%, and each of the eight combinations would occur 12.5% of the time. Instead, percentages range from 0 to 32%. All values are significantly different from chance (stochastic behavior) with a $P < 0.01$, as determined by a permutation test.

Table S2. Percentage of trials in which the ipsilateral or contralateral hand moved first, moved into or out of the RF, and was accompanied by an initial saccade directed into or out of the RF

			Movement instruction and hand that moved first			
			Contralateral hand into RF (ipsilateral hand out of RF)		Contralateral hand out of RF (ipsilateral hand into RF)	
Animal	First saccade direction	Total, %	Contralateral hand moved first, %	Ipsilateral hand moved first, %	Contralateral hand moved first, %	Ipsilateral hand moved first, %
M1	Into RF	35	8	8	8	11
	Out of RF	65	11	22	17	15
M2	Into RF	44	13	8	7	16
	Out of RF	56	9	20	20	8

Values are expressed as the percentage of saccade choices into or out of the RF, as a function of target location and reach order, averaged across all cells. The systematic biases seen in Table S1 were mitigated by the fact that we recorded from both hemispheres. These are the same data shown in Table S1 but now sorted based on direction relative to the recorded hemisphere rather than absolute direction. Here each possible split is represented from 7 to 22% of the time, i.e., more uniformly than when sorted based on left versus right. "Ipsilateral" and "contralateral" hands refer to the hand with respect to the recorded hemisphere. Values are expressed as mean of the individual cell values.