

# Bilateral Spike-Triggered Average Effects in Arm and Shoulder Muscles from the Monkey Pontomedullary Reticular Formation



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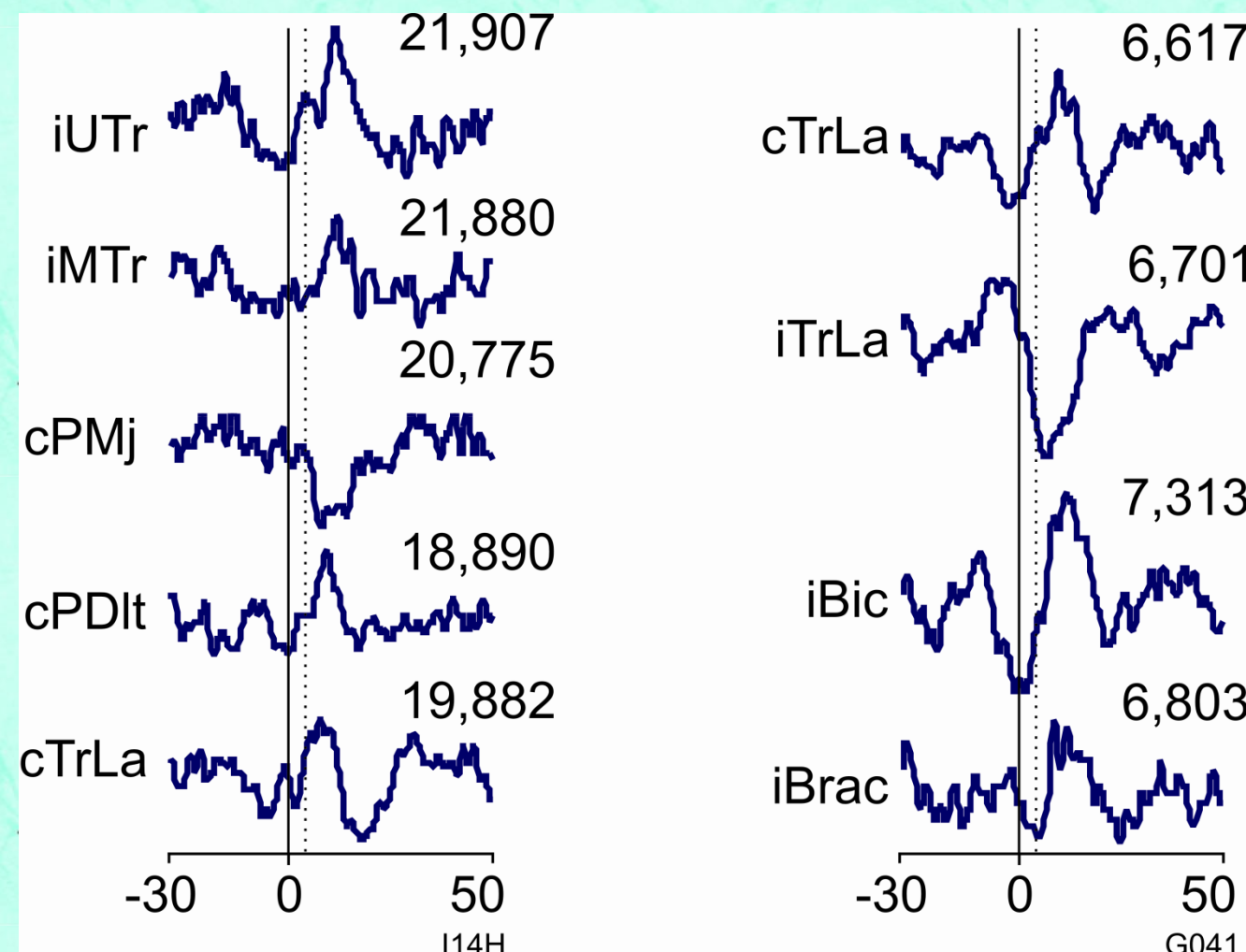
## Abstract

Pontomedullary reticular formation (PMRF) neurons (309) were recorded simultaneously with electromyographic (EMG) activity from arm and shoulder muscles in four monkeys performing arm reaching tasks. Spike-triggered averages (SpikeTAs) were compiled for 292 neurons (3,836 neuron-muscle pairs). Fourteen PMRF neurons located in a region ventral to the abducens nucleus produced 42 significant SpikeTA effects in arm and shoulder muscles. Of these 14 PMRF neurons, 9 produced SpikeTA effects bilaterally. Overall, PMRF neurons facilitated ipsilateral flexors and contralateral extensors, while suppressing ipsilateral extensors and contralateral flexors. Spike- and stimulus-triggered averaging effects obtained from the same recording site were similar. These findings indicate that single PMRF neurons can directly influence movements of both upper limbs.

## Methods

Four male *Macaca fascicularis* monkeys performed an instructed-delay arm reaching task as single neural-unit activity was recorded from the PMRF simultaneously with EMG activity in arm and shoulder muscles. Monkeys I and G reached with either the left or right arm to targets presented on a touch screen monitor; monkeys C and D performed a center-out planar reaching task with the right arm. Recording sites were ventral to the abducens nucleus, dorsal to the inferior olive and/or medullary pyramids, medial to the facial nucleus (~4 mm lateral to the midline), and at least 1 mm lateral to the midline. Recording sites were confirmed with post-mortem anatomical reconstructions. For monkeys I and G, EMG electrodes were implanted bilaterally in Flexor Carpi Radialis (FCR), Extensor carpi radialis (ECU), Brachioradialis (Brac), Biceps (Bic), Triceps (Tri), deltoids (anterior-ADit; posterior-PDIt), Pectoralis Major (PMj), Lats (Lat), and the upper and middle trapezius (MTr, UTr). For monkeys C and D, Bic, Tri, PDIt, and ADit were implanted ipsilaterally; the UTr and MTr were implanted bilaterally. In total, EMG data from 43 arm and shoulder muscles were analyzed with SpikeTA; 20 were ipsilateral, 23 were contralateral. Spike-triggered averages (SpikeTAs) were compiled off-line for each neuron-muscle pair. EMG was rectified and averaged over an 80 ms interval beginning 30 ms before the spike and ending 50 ms following the spike, smoothed with a five-point flat filter, and baseline ramps were removed by subtracting their slope from the final average. SpikeTAs were analyzed with multi-fragment statistical analysis (MFSA) (Poliakov and Schieber 1999), where the spike train was divided into smaller fragments to compile fragment SpikeTAs. EMG peaks (facilitation, Fac) or troughs (suppression, Spr) in the test period (3 ms to 15 ms) were considered SpikeTA effects when the test period EMG mean was significantly different ( $p < 0.05$ ) from the EMG mean of two flanking control periods (-8 ms to 3 ms; 15 ms to 27 ms) across all fragments. A neuron's SpikeTA effects were considered statistically significant if at least one neuron-muscle pair was significant after Bonferroni correction ( $p < 0.003$ ). For each SpikeTA effect, we measured onset latency, peak width at half maximum (PWHM), and the peak and mean percent increase above baseline from onset to offset.

## 1. Single PMRF neurons produce SpikeTA Effects in arm and shoulder muscles bilaterally



•309 neurons were recorded throughout PMRF; 292 analyzed with SpikeTA, 3,836 neuron-muscles pairs

•14 PMRF neurons produced 42 SpikeTA effects: 23 facilitation, 19 suppression

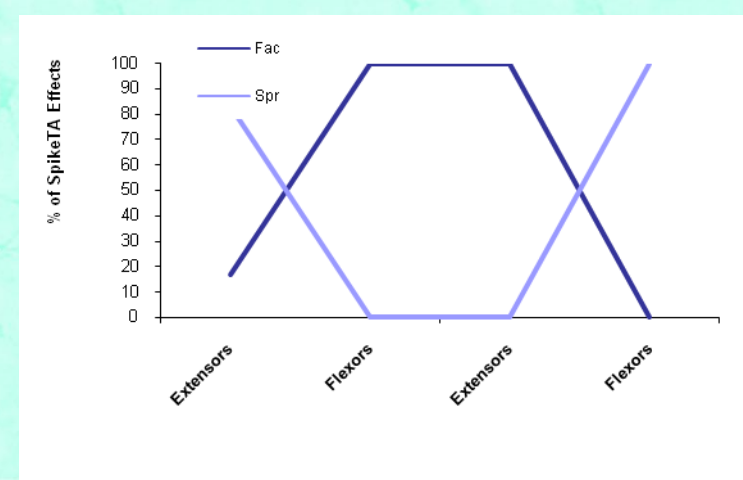
•On average, PMRF neurons produced a SpikeTA effect in 28.5% of the simultaneously recorded muscles

•9 of the 14 neurons produced SpikeTA effects bilaterally: no significant difference between the number of ipsilateral (24/312) and contralateral (18/234) neuron muscle pairs with SpikeTA effects ( $p > 0.05$ ;  $\chi^2$  test)

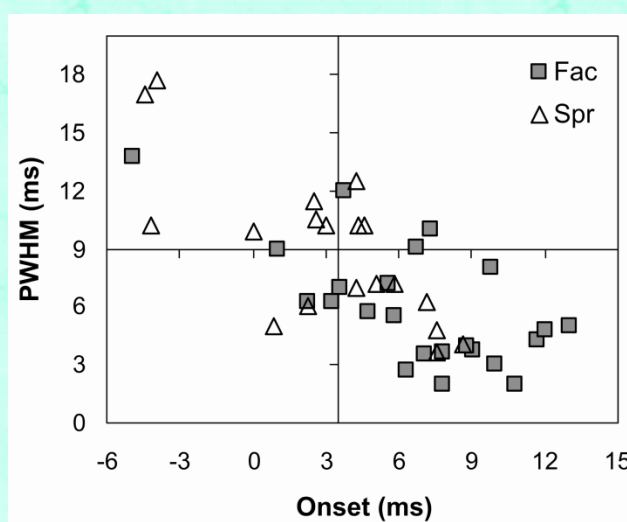
•The proportion of facilitative versus suppressive SpikeTA effects did not differ on the ipsilateral (15 facilitative, 13 suppressive effects) versus contralateral (8 facilitative, 6 suppressive) side ( $p > 0.05$ , Fisher's exact test)

## 2. PMRF neurons produce reciprocal SpikeTA effects between the flexors and extensors of the arm and shoulder

•In general PMRF SpikeTA effects facilitated ipsilateral flexors and contralateral extensors; but suppressed ipsilateral extensors and contralateral flexors ( $p < 0.05$ , Fisher's exact tests)



## 3. Temporal and amplitude characteristics of PMRF neuron SpikeTA effects

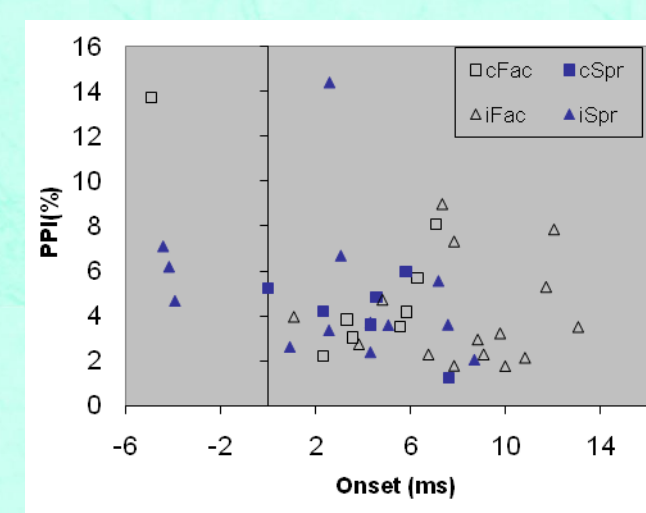


•PMRF neurons produced SpikeTA effects that were consistent with a continuum between pure and synchrony SpikeTA effect types.

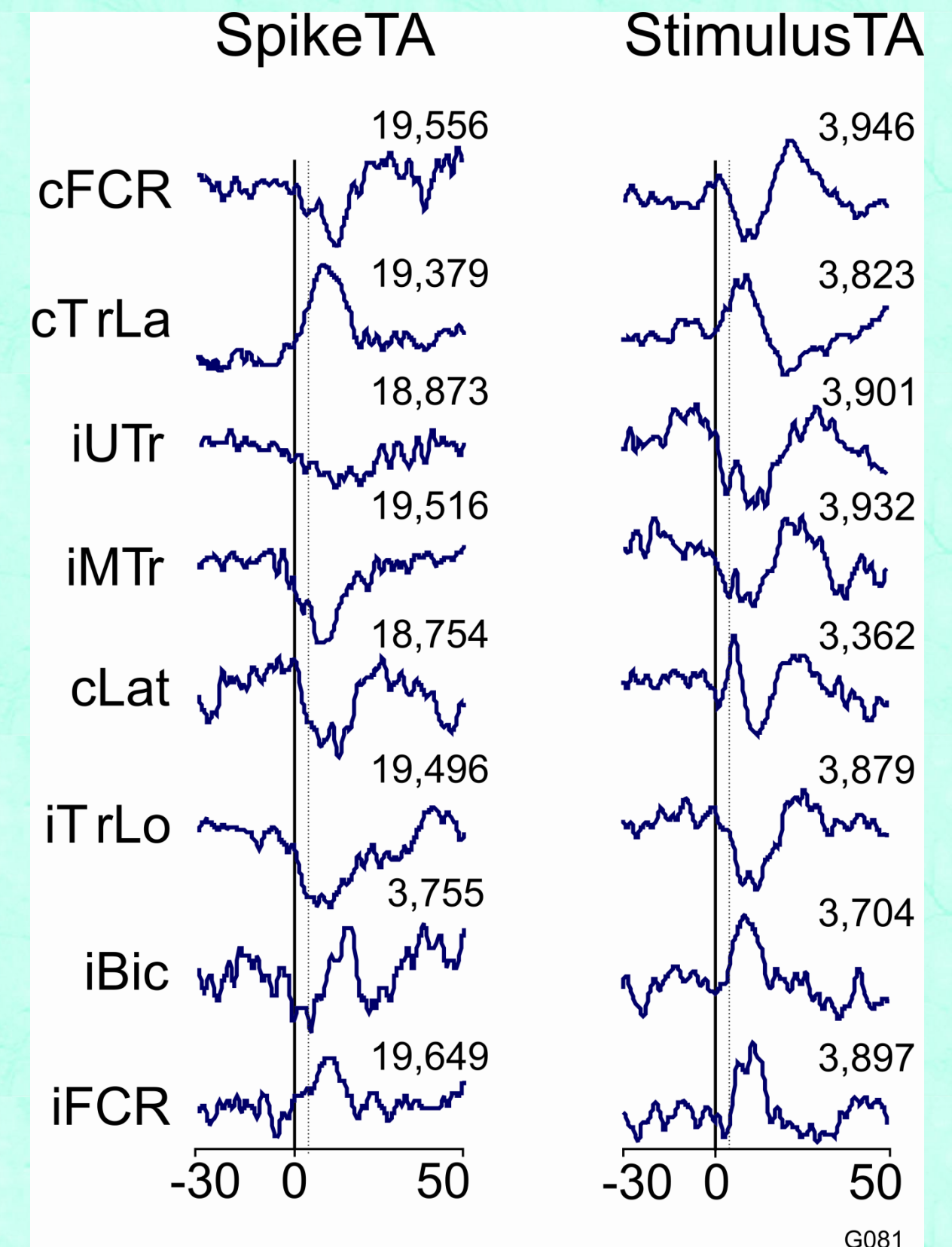
•Mean onset of suppression (3.1–3.9 ms) was earlier than facilitation (6.7–4.1 ms) ( $p < 0.01$ ,  $t$ -test)

•Facilitative SpikeTA effects: PPI ranged from 1.7 to 13.7% (mean SD, 4.6 2.9); MPC ranged from 1.4 to 6.8% (3.2–1.7)

•Suppressive SpikeTA effects: PPI ranged from -1.3 to -14.4% (-4.8–2.8); MPC ranged from -0.8 to -10.3% (-3.3–2.0)



## 4. PMRF SpikeTA effects are similar to StimulusTA effects



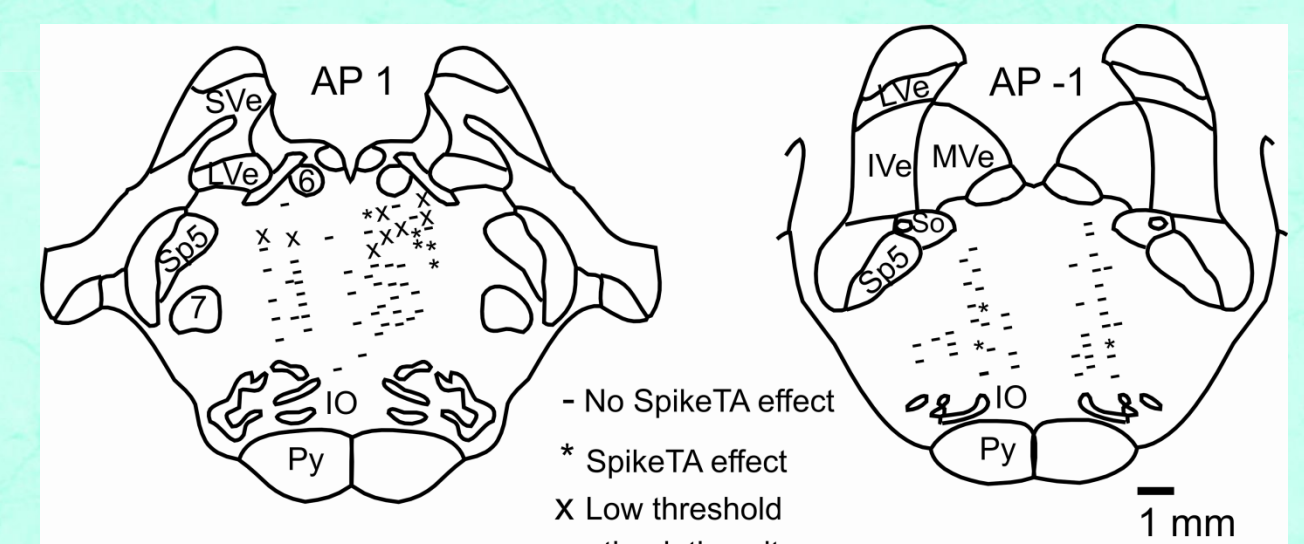
•StimulusTA was attempted at 13 of the 14 sites where PMRF neurons produced SpikeTA effects. 39 of these 161 neuron-muscle pairs produced SpikeTA effects.

•In 29 cases, both StimulusTA and SpikeTA effects were produced in the same muscle from a single PMRF site. 19 of these SpikeTA - StimulusTA effect pairs were the same sign (i. e. fac. Vs. fac.), the remaining 10 were opposite in sign ( $p > 0.0001$ ;  $\chi^2$  test)

## 5. Similar spatial location of PMRF neurons producing SpikeTA effects

•10 neurons producing SpikeTA effects were recorded in a rostral-dorsal PMRF region ~2–4 mm ventral and slightly rostral (AP, 1 to 2) to the abducens nucleus

•4 neurons recorded in a PMRF region 5–7 mm ventral and caudal (AP, 0 to -1) to the abducens nucleus



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## Conclusions

1. In the monkey, PMRF neurons produce SpikeTA effects in the arm and shoulder muscles bilaterally.
2. PMRF neuron SpikeTA effects were produced throughout the arm and shoulder, including some wrist muscles.
3. SpikeTA effects were sometimes organized in reciprocal patterns between flexors and extensors, both within the same limb and between limbs. The most common reciprocal responses were facilitation of flexors and suppression of extensors ipsilaterally, and suppression of flexors and facilitation of extensors contralaterally.
4. Most PMRF neurons producing SpikeTA effects were located in a limited region ventral to the abducens nucleus (NRGc).